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ABSTRACT

This syllabus, which has evolved from the New York State Experimental Biology program, includes a basic core and six optional extended areas designed to be interesting and meaningful to the types of students currently taking the Regents Examination in Biology. The seven core unit topics are: (1) The Study of Life; (2) Maintenance in Animals; (3) Maintenance in Plants; (4) Reproduction and Development; (5) Transmission of Traits from Generation to Generation; (6) Evolution and Diversity; and (7) Plants and Animals in their Environment. The six optional extended areas include: (1) Biochemistry, (2) Human Physiology, (3) Reproduction and Development, (4) Modern Genetics, (5) Modern Evolution Theory, and (6) Ecology. Appendices contain a reference bibliography, a laboratory reference list, and a list of laboratory exercises. This publication could be used in developing and teaching biology and related courses in many different settings. (MR)

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BIOLOGY

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BIOLOGY

A Secondary School Syllabus With

Major Emphasis on Fundamental

Concepts

1976 Reprint

The University of the State of New York
THE STATE EDUCATION DEPARTMENT
Bureau of General Education Curriculum Development
Albany, New York 12234

FOREWORD

This syllabus which has evolved from the New York State Experimental Biology program includes a basic core and six optional extended areas. The teacher may select the three extended areas best suited to local conditions. Further details of the core program and the optional areas will be found on page v. The material presented is a result of the deliberations and recommendations of the Biology Syllabus Revision Committee which was charged with the responsibility of preparing a flexible course of study that would be interesting and meaningful to the types of students currently taking Regents Biology.

It is the intent of this course to provide students with an awareness of the natural world, basic scientific concepts, stimulation of inductive reasoning, and a basic understanding of biological processes and generalizations.

The original draft of the experimental biology syllabus was written during the summer of 1964, and was used on a trial basis during the 1964-65 academic year in 33 schools. During the 1965-68 school years approximately 120 schools used the experimental biology syllabus materials, and suggestions for changes and improvements were submitted by many of the teachers involved. Participating teachers have played a vital role in the development, implementation, and evaluation of the present syllabus.

The members of the Biology Revision Committee are: Lawrence Bach, Ithaca High School; Emanuel Blank, LaFayette High School, New York City; Ruth Horn, Syosset High School; David Kraus, Far Rockaway High School, New York City; Richard Lape (deceased), Amherst Central School; Jean Reid, Irondequoit High School; Ralph Sonen, Northport High School; Emery Will, State University College at Oneonta.

During the summer of 1964, a writing team consisting of Mrs. Ruth Horn, Jean Reid, and Ralph Sonen of the committee, and Fred Bohensky, Samuel Tilden High School, New York City, prepared the original draft. Ralph Sonen and Monroe Cravats, LaFayette High School, New York City, prepared the 1965 edition. Mrs. Horn and Daniel Kammerman, Bay Ridge High School, New York City, prepared the 1966 edition. Ann D. Muehleck, Colonie Central High School, and Joseph R. Kelly, Milne School, SUNY at Albany, prepared the 1967 and the present edition under the direction of William A. Calhoun (retired) of the Bureau of Science Education. Robert F. Zimmerman, Associate in Secondary Curriculum, edited and prepared the manuscript for publication.

Herbert Bothamley, *Chief*
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Content and sequence

This course in biology is designed to provide broad general understanding of the fundamental principles of biology and to provide an extension of understanding in selected areas. The course consists of a basic core of seven units and teacher-selected extended treatment areas. Approximately 70 percent of the total classroom time should be spent on the core areas with the remainder of the time used in the development of any three extended areas.

Each extended treatment area is set off in boxes. The code below is used to identify specific areas:

Code	Extended Areas	Location
BC	Biochemistry	Units 1, 2, 3
HP	Human Physiology	Unit 2
RD	Reproduction and Development	Unit 4
MG	Modern Genetics	Unit 5
ME	Modern Evolution Theory	Unit 6
EC	Ecology	Unit 7

It should be noted that the extended treatment area of biochemistry (BC) appears in Units 1, 2, and 3.

Since the block program of the Junior High School Science Program features emphasis on human physiology in Blocks A and B, it is expected that in most schools the contents of this area will have been treated prior to the tenth grade. The extended treatment area of human physiology (HP) may be deleted from the syllabus within a few years.

The sequence in the next column may be used to establish a basic time schedule for the core:

Core	Topics	*Percent of Total Course Time
Unit 1	The Study of Life	5 - 10
Unit 2	Maintenance in Animals	15 - 25
Unit 3	Maintenance in Plants	8 - 12
Unit 4	Reproduction and Development	8 - 12
Unit 5	Transmission of Traits from Generation to Generation	8 - 12
Unit 6	Evolution and Diversity	5 - 10
Unit 7	Plants and Animals in Their Environment	5 - 10

*including laboratory work and tests

The order of presentation used in the syllabus indicates one of several possible teaching sequences. Any sequence that presents a logical development of biological principles may be followed.

Organization of the syllabus

The material in this syllabus is organized under three major headings:

COLUMN 1 - TOPICS - This column contains the topical outline. Topics included in the extended areas are enclosed in boxes in all three columns.

COLUMN 2 - UNDERSTANDINGS AND FUNDAMENTAL CONCEPTS - This column outlines the basic subject matter and concepts of the course for both the basic core and the extended areas. All the concepts in the basic core are subject to testing on Parts I and II of the Regents Examination. Those understandings and fundamental concepts which are boxed are required for extended areas only.

COLUMN 3 - SUPPLEMENTARY INFORMATION - Information in this column is directed to the teacher and is not subject to testing.

Appendix I contains a reference bibliography.

Appendix II contains a list of laboratory references.

Appendix III contains a list of laboratory exercises.

Relationship of the Biology Syllabus to the Regents Examination in Biology.

The Regents Examination in Biology will have two major parts. Part I will consist of questions based ONLY on the basic core, and Part II questions will consist of items based on the extended areas. Part II questions may also relate to core topics.

Laboratory

The subjects of the suggested laboratory experiences (Appendix III) were chosen to facilitate development of the major concepts of the syllabus.

Many subjects were listed to make it possible to adapt the program to the individual school. It is realized that there are many other possible laboratory exercises, and these may be utilized if the teacher desires.

Laboratory reference works listed in Appendix II will provide the teacher with a range of exercises for use or modification.

LABORATORY EXPERIENCES REPRESENTING AT LEAST 30 FULL-TIME LABORATORY PERIODS ARE REQUIRED. WHILE THE MINIMUM LABORATORY REQUIREMENT CAN BE MET BY PERFORMING 30 EXPERIENCES REQUIRING 30 LABORATORY PERIODS, IT CAN ALSO BE MET BY SPENDING 30 LABORATORY PERIODS ON A LESSER NUMBER OF EXPERIMENTS. IN ADDITION, A SATISFACTORY REPORT OF EACH LABORATORY EXPERIENCE IS REQUIRED

Time requirement

The recommended minimum time required for this course is six periods per week. This time allotment should include at least one double period per week for laboratory work.

Unit 1 - The Study of Life (Pages 1 - 16)

I. The Concept of Life
A. Definition of life
B. Activities of life
1. Nutrition
2. Transport
3. Respiration
4. Excretion
5. Synthesis
6. Regulation
7. Growth
8. Reproduction

II. The Units of Life
A. Cell theory
1. Historical background
2. Currently accepted concepts
3. Exceptions to concepts
B. Cell study
1. Investigational techniques
a. Instruments used in cell study
b. Measurement
2. Structural components

III. The Chemistry of Life
A. Chemical elements in living matter
B. Chemical compounds in living matter
1. Inorganic compounds
2. Organic compounds
a. Carbohydrates
(1) Composition

BC (2) Structure

b. Lipids
(1) Composition

BC (2) Structure

c. Proteins
(1) Composition

BC (2) Structure

d. Nucleic acids
(1) Composition

BC (2) Structure
C. Chemical activity in living matter
1. The role of enzymes
a. Structure
(1) Protein nature
(2) Active site
b. Function
(1) Enzyme-substrate complex
(2) "Lock-and-key" model
c. Factors influencing enzyme action
(1) pH
(2) Temperature
(3) Relative amounts of enzyme and substrate
2. Reactions
a. Dehydration synthesis
b. Hydrolysis

Unit 2 - Maintenance in Animals (Pages 17 - 45)

I. Nutrition
A. Process
1. Ingestion
2. Digestion
a. Mechanical aspects
b. Chemical aspects
(1) Enzyme action
(2) Outcome
B. Adaptations
1. Protozoa
2. Hydra
3. Earthworm
4. Grasshopper
5. Man

HP

C. Human digestion
1. Digestive system
a. The alimentary canal
b. Digestive glands
2. Digestive function

II. Transport
A. Process
1. Absorption
a. Structure of the cell membrane
b. Function of the cell membrane
(1) Passive transport
(2) Active transport and pinocytosis
2. Circulation
B. Adaptations
1. Protozoa
2. Hydra
3. Earthworm
4. Grasshopper
5. Man

HP

C. Human circulation
1. Circulatory system
a. Structures
(1) Heart
(2) Arteries
(3) Capillaries
(4) Veins
(5) Lymph vessels
b. Fluids
(1) Blood
(2) Lymph
2. Circulatory function
a. Transport
b. Protection
(1) Clotting
(2) Phagocytosis
(3) Immunological reactions

III. Respiration
A. Process
1. Cellular level
a. Aerobic respiration
(1) Description

BC

(2) Chemical aspects

b. Anaerobic respiration
(1) Description

BC

(2) Chemical aspects

2. Organism level
B. Adaptations
1. Protozoa
2. Hydra
3. Earthworm
4. Grasshopper
5. Man

HP

C. Human respiration
1. Respiratory system
2. Respiratory function

IV. Excretion
A. Process
B. Adaptations
1. Protozoa
2. Hydra
3. Earthworm
4. Grasshopper
5. Man

HP

C. Human excretion
1. Excretory system
2. Excretory function

17

a. Lungs
b. Liver
c. Skin
d. Kidney

V. Synthesis
A. Process
B. Products
1. Secretions
a. Enzymes
b. Hormones
c. Neurohumors
d. Other
2. Structural compounds
C. Outcome

HP
D. Human synthesis
1. Limitations
2. Synthesis in relation to diet

VI. Regulation
A. Process
1. Nervous control
a. Stimulus and response
b. Transmission of nerve impulses
(1) Neurons
(2) Synapses
(3) Neurohumors
2. Endocrine control
a. Hormones
b. Effects
3. Comparison of nervous and endocrine systems
B. Adaptations
1. Nervous systems
a. Protozoa
b. Hydra
c. Earthworm
d. Grasshopper
e. Man
2. Endocrine systems

HP
C. Human nervous regulation
1. Nervous system
a. Structural units
(1) Sensory neurons
(2) Associative neurons
(3) Motor neurons
b. Organization
(1) Nerves
(2) Ganglia and plexuses
(3) Spinal cord
(4) Brain
(a) Cerebrum
(b) Cerebellum
(c) Medulla
2. Nervous functions
a. Involuntary behavior
(1) Reflexes
(2) Conditioned behavior
b. Voluntary behavior
D. Human endocrine regulation
1. Endocrine system
2. Endocrine function
a. Thyroid gland
b. Parathyroid glands
c. Adrenal glands
d. Pituitary gland
e. Pancreas
f. Sex glands

VII. Locomotion
A. Process
B. Adaptations
1. Protozoa
2. Hydra
3. Earthworm
4. Grasshopper
5. Man

HP

C. Human locomotion
1. Locomotive system
a. Bones
b. Muscles
c. Tendons
d. Ligaments
2. Locomotive function

Unit 3 - Maintenance in Plants (Pages 46 - 55)

I. Nutrition
A. Autotrophic nutrition
1. Photosynthesis
a. Process
(1) Description

BC

(2) Chemical aspects

b. Site

BC

2. Chemosynthesis

B. Heterotrophic nutrition
II. Digestion
III. Transport
A. Roots
1. Root hairs
2. Xylem
3. Phloem
B. Stems
C. Leaves
IV. Respiration
A. Types
1. Aerobic
a. Description

BC

b. Chemical aspects

2. Anaerobic
a. Description

BC

b. Chemical aspects
(1) Alcoholic fermentation
(2) Lactic acid fermentation

B. Energy yield
V. Excretion
VI. Synthesis
A. Process
B. Products
1. Structural
2. Other
C. Outcome
VII. Regulation
A. Production of auxins
B. Effects of auxins

Unit 4 - Reproduction and Development (Pages 56 - 71)

I. Cell Division
A. Mitotic cell division
1. Processes
a. Mitosis
b. Cytoplasmic division
2. Comparison between plant and animal cell division
B. Meiotic cell division
1. Process
2. Comparison with mitotic cell division
II. Reproduction
A. Asexual
1. Types
2. Results
B. Sexual
1. Animals
a. Gamete formation
(1) Spermatogenesis
(2) Oogenesis

x

b. Zygote formation
(1) External fertilization
(2) Internal fertilization
c. Embryo formation
2. Plants
a. Gamete formation
(1) Spermatogenesis
(2) Oogenesis
b. Zygote formation
(1) Pollination
(2) Fertilization
c. Embryo formation

RD

III. Development
A. Animals
1. Embryonic development
a. Cleavage and differentiation
b. Site of embryonic development
(1) External
(a) In water
(b) On land
(2) Internal
(a) Placental animals
(b) Nonplacental animals
2. Postembryonic development
B. Plants
1. Seed formation
2. Seed development
IV. Reproduction and Development in Man
A. Reproduction
1. Gamete formation
a. Male reproductive system
(1) Structure
(2) Function
b. Female reproductive system
(1) Structure
(2) Function
(a) Role of hormones

(b) Menstrual cycle
2. Zygote formation
B. Development
1. Prenatal
2. Postnatal

Unit 5 - Transmission of Traits from Generation to Generation (Pages 72 - 83)

I. Mendelian Heredity
A. Dominance
B. Segregation
C. Independent assortment
II. The Gene-Chromosome Theory
A. Dominance
B. Segregation and recombination
C. Independent assortment and recombination
III. Patterns of Heredity
A. Incomplete dominance
B. Sex determination
C. Sex linkage
D. Multiple alleles
IV. Mutations
A. Types
1. Chromosomal mutations
a. Crossing-over
b. Nondisjunction
c. Polyploidy
d. Other chromosomal mutations
2. Gene mutations
B. Mutagenic agents
V. Interaction of Heredity and Environment
VI. Heredity and Man
A. Human genetics
1. Phenylketonuria
2. Sickle-cell anemia
3. Blood groups
B. Plant and animal breeding

VII. Modern Genetics
A. DNA as the hereditary material
1. Evidences
2. DNA structure
a. Nucleotides
b. Watson-Crick model

MG

B. Gene action
1. DNA replication
2. Gene control of cellular activities
a. RNA
b. DNA and RNA codes
c. Protein synthesis
d. The "one gene-one enzyme" hypothesis
e. Individuality of organisms as related to their DNA and RNA codes
C. Gene mutations
1. Characteristics
2. Mechanisms
D. Cytoplasmic inheritance

Unit 6 - Evolution and Diversity (Pages 84 - 93)

I. Evidence for Evolution
A. The fossil record
B. Comparative anatomy
C. Comparative embryology
D. Comparative biochemistry
E. Geographic distribution
II. Theories of Evolution
A. Lamarck's theory
B. Darwin's theory
C. Modern theory
1. Production of variations

ME

2. Population genetics
a. Population
b. Gene pool
3. Transmission of variations
a. Factors influencing transmission
(1) The environment
(2) Isolation
b. Patterns of change
(1) Change within a species
(2) Development of new species

III. A Modern Classification System
IV. Origin and Early Evolution of Life
A. The heterotroph hypothesis
1. Assumptions
a. Raw materials
(1) Inorganic compounds
(2) Energy sources
b. Synthesis
c. Nutrition
d. Reproduction
B. Heterotroph to autotroph
C. Anaerobe to aerobe

Unit 7 - Plants and Animals in Their Environment (Pages 94 - 108)

I. Ecology
A. Physical factors in the environment
B. Biotic factors in the environment
II. Biotic organization
A. Population
B. Community
C. Ecosystem
1. Interactions

a. Specific relationships
b. General relationships
(1) Energy flow
(2) Material cycles
2. Maintenance
3. Changes
a. Pioneer organisms
b. Climax community

SC

D. World biomes
1. Terrestrial
2. Aquatic
a. Marine
b. Fresh water
E. Biosphere
III. Biosphere and Man
A. Past and present
1. Negative aspects
2. Positive aspects
B. The future

Topics	Understandings and Fundamental Concepts	Supplementary Information
I. The Concept of Life		
A. Definition of life	No one, all-inclusive, definition of life has proved satisfactory. Extensive examination of many living things has, however, produced some characteristics of life which are generally agreed upon.	
B. Activities of life	The characteristic activities associated with living organisms are known as physiological functions and include: nutrition, transport, respiration, excretion, synthesis, regulation, growth, and reproduction. The term metabolism is used to describe the chemical activities that occur in an organism.	
1. Nutrition	Nutrition involves those activities of an organism by which it procures raw materials from its environment and processes them so as to make them available for physiological activities.	
2. Transport	Transport involves the intake (absorption) and distribution (circulation) of essential compounds throughout an organism.	
3. Respiration	Respiration involves the conversion of the potential energy of organic compounds to a form that is suitable for the various energy-requiring activities of an organism.	
4. Excretion	Excretion involves the removal of harmful (or potentially harmful) substances which form as waste products of metabolism in an organism.	
5. Synthesis	Synthesis involves those chemical activities by which complex molecules are created from simple compounds.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
6. Regulation	Regulation involves the control of the various physiological activities of an organism in such a way as to maintain stability through coordinated activity in a constantly changing environment.	
7. Growth	Growth is the increase in size of an organism that results from the synthesis and organization of organic compounds into new materials and structures.	
8. Reproduction	Reproduction is the unique characteristic of living organisms involving the production of new individuals essentially similar to those producing them.	
	An organism is a living system that carries on the functions described above. In summary it may be said that organisms: . are complex and highly organized (even the simplest ones) . require and use energy . are "chemical factories" . receive and respond to stimuli . are relatively stable regulatory systems which cause certain portions of the environment to pass through them in an organized manner (principle of homeostasis)	
II. The Units of Life		
A. Cell theory		
1. Historical background	During the 18th and 19th centuries biologists extensively examined a wide variety of living things with the aid of the light microscope. Data collected from these investigations served as the basis for the statement of the cell theory.	During the long period of extensive cell investigation, microscopes were steadily improved, permitting increased accuracy in cell investigations.
2. Currently accepted concepts	Cells are the unit of structure of living things. Cells are the unit of function of living things. Cells arise from living cells.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
3. Exceptions to concepts	Two exceptions to these concepts which do not, however, destroy the usefulness of the theory, are: The first cell could not have arisen from a previously existing cell. There may be other units of structure and function. Examples of such units are self-duplicating structures (mitochondria and chloroplasts), modified organizational patterns (multinucleate organization of slime molds, bread molds, and certain types of muscle cells), and viruses.	
B. Cell study		
1. Investigational techniques	In the more than 100 years since the statement of the cell theory, biologists have continued to study cells and, as new techniques and instrumentation have been developed, increased understanding has resulted. The development of staining technology in the latter half of the 19th century made possible the study of structures not previously observed. Also, new and improved instruments have greatly aided understanding of cell anatomy and physiology.	
a. Instruments used in cell study	The compound microscope, electron microscope, phase contrast microscope, interference microscope, ultracentrifuge, and microdissection instruments are some of the tools that have aided biologists in gaining a more complete picture of the structures and functions of cells.	Discussion of these instruments should be limited to their application to cell study and should be used for developing the point that the understanding of the cell, as biologists know it today, rested on instrument development. *Details of construction of these instruments are limited to the compound microscope.*

Topics	Understandings and Fundamental Concepts	Supplementary Information
b. Measurement	The minute size of cell structures requires small units of measurement for recognition and comparison. The micron (μ) is a unit of microscopic measurement. One thousand microns is equal to one millimeter.	The use of larger units in discussing cell structures is cumbersome (e.g., the diameter of a red blood cell is more conveniently expressed as 7μ than as 0.0000002 feet).
2. Structural components	In cells, various specialized functions occur in substructures known as organelles. Some major organelles and their related functions are:	

cell wall	. protects . supports plant cell and maintains constant shape
cell and nuclear membranes	. controls transport of materials into and out of the cell and nucleus . isolates cellular and nuclear materials
cytoplasm	. provides a watery environment in which most life activities take place
endoplasmic reticulum	. provides channels, through which transport of materials occurs in the cytoplasm, and interfaces, where interactions may occur
ribosomes	. act as sites of protein synthesis
mitochondria	. act as sites of cellular respiration
vacuoles	. act as reservoirs for water and dissolved materials
chloroplasts	. contain energy-accumulating pigments in plant cells . act as sites for synthesis of organic compounds from inorganic raw materials
centrosome	. contains centrioles which are functional during the division of animal cells
nucleus	. acts as information center for cell division and other cell activities

Topics	Understandings and Fundamental Concepts	Supplementary Information
	chromosomes . contain the hereditary material of a cell . are the agents of distribution of hereditary information nucleolus . may have a role in protein synthesis	

It is expected that students will have some background in basic chemistry before coming into the biology course. The basic information should include such concepts as: atom, molecule, element, compound, acid, base, salt, ionic bonding, covalent bonding, and so forth. Much useful information for the development of basic chemistry understandings may be found in Science 7,8,9 - Block J, and Block L (section VII - Organic Chemistry).

III. The Chemistry of Life		
A. Chemical elements in living matter	The cell is a complex "chemical factory." It is composed of some of the same elements found in the non-living environment: carbon, hydrogen, oxygen, nitrogen, sulfur, phosphorus, and traces of magnesium, iodine, iron, and calcium.	
B. Chemical compounds in living matter	Organisms consist of inorganic and organic compounds.	
1. Inorganic compounds	The principal inorganic compounds are water, salts, inorganic acids, and bases.	The importance of water as a solvent for other compounds should be stressed.
2. Organic compounds	Organic compounds are unique to life and are always part of, or a product of, living systems. The principal organic compounds include carbohydrates, lipids, proteins, and nucleic acids.	
a. Carbohydrates		

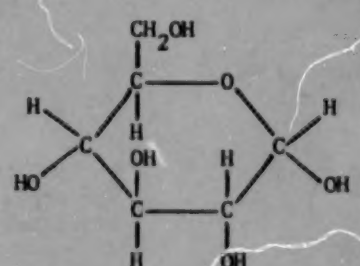
Topics	Understandings and Fundamental Concepts	Supplementary Information
(1) Composition	Carbohydrates consist of the elements carbon, hydrogen, and oxygen. Hydrogen and oxygen are present in a 2:1 ratio.	
	The principal carbohydrates include sugars, such as glucose, maltose, and sucrose, and starches	The names of carbohydrates typically end in -ose, e.g., glucose, maltose, sucrose, and so forth.

BC

(2) Structure

In general, sugars are low-molecular-weight compounds which are sweet and water-soluble. Included among the sugars are monosaccharides, such as glucose, fructose, and galactose, and disaccharides, such as maltose, lactose, and sucrose.

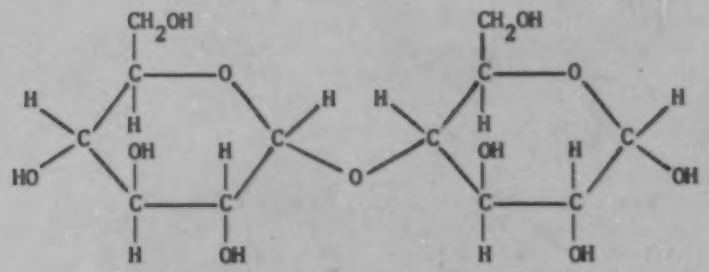
The structural formulas of a representative monosaccharide, glucose, and a disaccharide, maltose, are:



Glucose

Pupils will not be expected to produce structural formulas and should not memorize them. However, it is expected that pupils will be able to recognize the compounds whose structural formulas are shown.

Topics	Understandings and Fundamental Concepts	Supplementary Information



Maltose

Glucose molecules may combine to form maltose by dehydration synthesis. When maltose is formed from two glucose molecules, a water molecule is released.

In general, starch is a high-molecular-weight substance which is only slightly soluble in water. It is a substance which is a complex of polysaccharide molecules made up of hundreds of repeating glucose units bonded together.

The polymer concept, i.e., very large molecules made up of repeating units of one type, is applicable here and should also be related to proteins and nucleic acids.

Cellulose and glycogen, other widely occurring polysaccharides, are also made up of repeating glucose units. They differ from starch in the manner in which the glucose units are bonded together.

Topics	Understandings and Fundamental Concepts	Supplementary Information

b. Lipids

(1) Composition

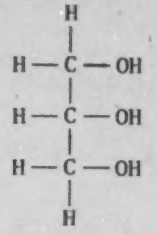
Lipids, like carbohydrates, consist of carbon, hydrogen, and oxygen. However, there is proportionately less oxygen in a lipid molecule. The ratio of hydrogen to oxygen is always much greater than 2:1 and is not constant from one lipid to another.

Lipids include fats, oils, and waxes.

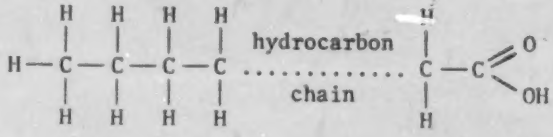
(2) Structure

Generally, lipids are small molecules and, unlike the other abundant organic compounds in living matter, are not polymers. Typically, lipids consist of three fatty acids bonded to a molecule of glycerol.

Glycerol is a 3-carbon alcohol with the following structural formula:



Fatty acids are long-chain hydrocarbon molecules which contain the characteristic organic acid group (-COOH) giving acid properties to the compounds. A general fatty acid structural formula appears below:



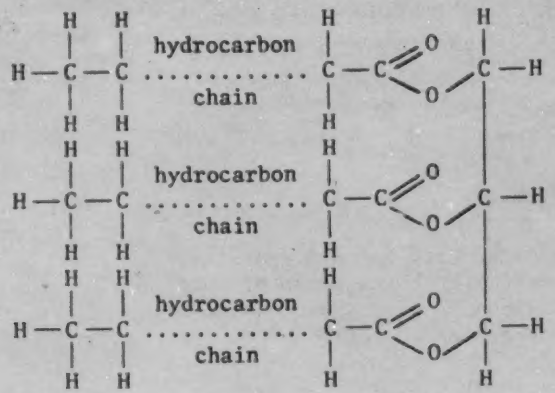
Characteristic groupings of atoms which show up frequently in different compounds are often referred to as groups, or, sometimes, side-groups. Examples include:

$-CH_3$ = methyl group

-COOH = carboxyl (acid) group

-OH = hydroxyl group

The characteristic lipid structure is indicated by the structural formula shown below:

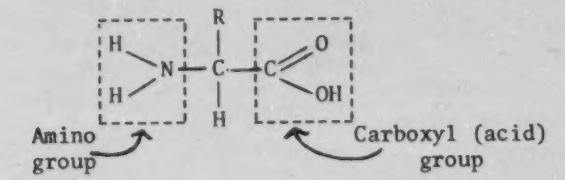


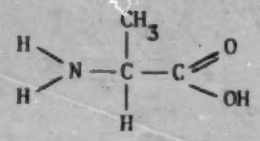
c. Proteins

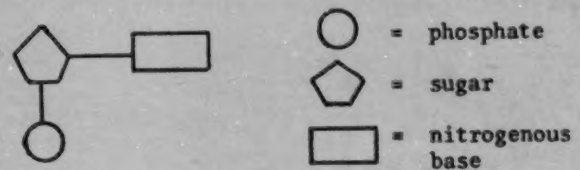
(1) Composition — Proteins contain carbon, hydrogen, oxygen, nitrogen, and, in many instances, sulfur.

(2) Structure — Proteins are high molecular weight polymers made up of repeating amino acid units. Although dozens of different amino acids have been identified, only 20 are typically found in living systems.

Amino acids have the general formula shown below and derive their name from the amino (NH_2) group and acid (COOH) group which are characteristic of the compounds.



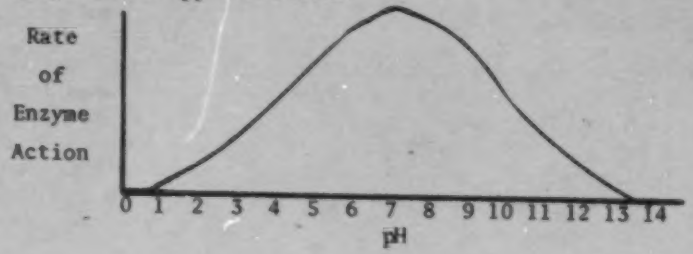
Topics	Understandings and Fundamental Concepts	Supplementary Information
	R represents a variable side group and is the basis for the variety of different amino acids. When R is a methyl group, for instance, the amino acid is alanine.  Alanine When amino acids bond to each other to form proteins, a C - N bond forms between the carboxyl group of one amino acid and the amino group of an adjacent amino acid. The C - N bond is known as a peptide bond, and a chain of amino acids thus bonded is known as a polypeptide. There is an extremely large (potentially infinite) number of different proteins. The bases for variability include: . differehces in the number and kinds of amino acids present . differences in the configuration of protein molecules due to attraction between different parts of the polypeptide chain producing a variety of shapes - straight chain, globules, helices, and so forth.	
d. Nucleic acids		
(1) Composition	Nucleic acids contain phosphorus in addition to carbon, hydrogen, oxygen, and nitrogen.	Treatment of nucleic acids here is limited to general properties as they compare with other significant groups of organic compounds. Detailed treatment appears in the Modern Genetics extension in Unit 5.
(2) Structure	Nucleic acids are the largest organic molecules known. They are high-molecular-weight polymers made up of repeating units known as nucleotides.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	Nucleotides, although unit molecules of the nucleic acids, are relatively complex molecules consisting of three subunits: phosphate, sugar, and nitrogenous base. Their basic organization may be represented as follows:  The sugar is always either ribose or deoxyribose. Ribose is found only in ribonucleic acids and deoxyribose in deoxyribonucleic acids.	
C. Chemical activity in living matter	Living matter is constantly in a state of dynamic chemical activity. Perhaps the most significant distinction between living and nonliving matter is the continuous, controlled chemical activity in living systems.	
1. The role of enzymes	The organic catalysts called enzymes are the principal means by which chemical activity in living systems is regulated. . Each chemical reaction occuring in an organism requires an enzyme. . Enzymes modify, by either accelerating or suppressing, the rate of reactions.	The concept of catalytic action may be demonstrated with an inorganic catalyst such as MnO_2 which greatly accelerates the reaction: $2H_2O_2 \xrightarrow{MnO_2} 2H_2O + O_2$ hydrogen peroxide — water — oxygen gas
a. Structure	There are thousands of different enzymes in cells. The great variety of enzymes is due to their protein nature.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
(1) Protein nature	All enzymes are either exclusively proteins or are proteins with attached, nonprotein, side groups known as coenzymes. Often, vitamins function as coenzymes.	When enzymes have both a protein and a nonprotein component, the protein part alone will not function in the absence of the coenzyme.
(2) Active site	Usually enzyme molecules are enormously larger than the molecules with which they interact. This observation, coupled with other data, has lead to the assumption that only a small portion of the enzyme molecules functions in enzyme action. This localized region is called the active site of the enzyme.	
b. Function	Little is known about the manner by which enzymes achieve their catalytic control over cell reactions. However, sufficient evidence has accumulated to permit biochemists to develop a model of enzyme action which is useful in visualizing the nature of their function and is consistent with the available evidence.	
(1) Enzyme-substrate complex	It is thought that, for an enzyme to affect the rate of a reaction, the following steps take place: . It must form an association with the substance or substances whose reaction rate it affects. These substances are known generally as substrates. . This association between enzyme and substrate is thought to involve a close physical association between the molecules, but does not involve bond formation between them. . The association between enzyme and substrate is known as an enzyme-substrate complex. . It is while the enzyme-substrate complex is formed that enzyme action takes place.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	. Upon completion of the reaction, enzyme and products separate, and the enzyme molecule is then available to form additional complexes.	Enzymes, like all molecules, (particularly large molecules) are subject to destructive forces which tend to make them disintegrate in time. Thus, a constant supply is needed by all cells.
(2) "Lock-and-key" model	The fact that a particular enzyme will usually only interact with a single type of substrate molecule has given rise to the "lock-and-key" model of enzyme specificity. Like a key that will only open a particular lock, a particular enzyme will usually only form a complex with one particular type of substrate molecule.	Specificity varies to some extent. In some instances an enzyme is highly specific for a single compound. In other instances enzymes exhibit group specificity and will form complexes with a number of related compounds.
c. Factors influencing enzyme action	The rate of enzyme action is not fixed, but varies according to conditions in the environment of the reacting substances. Such factors as pH, temperature, and relative amounts of enzyme and substrate determine the rate of enzyme action.	
(1) pH	The rate at which enzyme-regulated reactions occur varies according to the hydrogen ion (H^+) concentration in the environment.	
	. Hydrogen ion concentration is usually indicated by means of the pH scale.	
	. The pH scale extends from 0 - 14. A pH of 7 = neutral. Acids have a pH less than 7 and bases have a pH greater than 7.	pH is the negative logarithm of the mass of hydrogen ions in a liter of solution. If, for instance, a liter of a particular solution contains 10^{-7} grams H^+ ions, the pH = 7. ($\log_{10} 10^{-7} = -7$; the negative log would, therefore, equal 7.)

For many enzyme-controlled reactions a pH of 7 provides an environment for optimal rate of enzyme action. pH greater or less than 7 would tend to slow down the reaction rate. This situation is summarized in the graph which appears below:

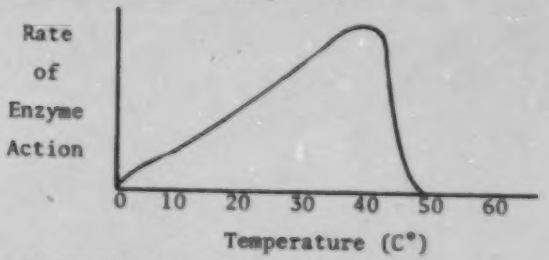


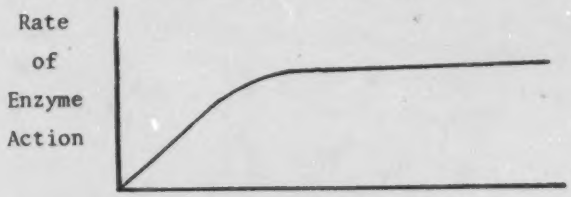
(2) Temperature

At low temperatures enzyme-controlled reactions tend to behave the same as uncatalyzed reactions. In general, as temperature increases, the rate of enzyme action increases.

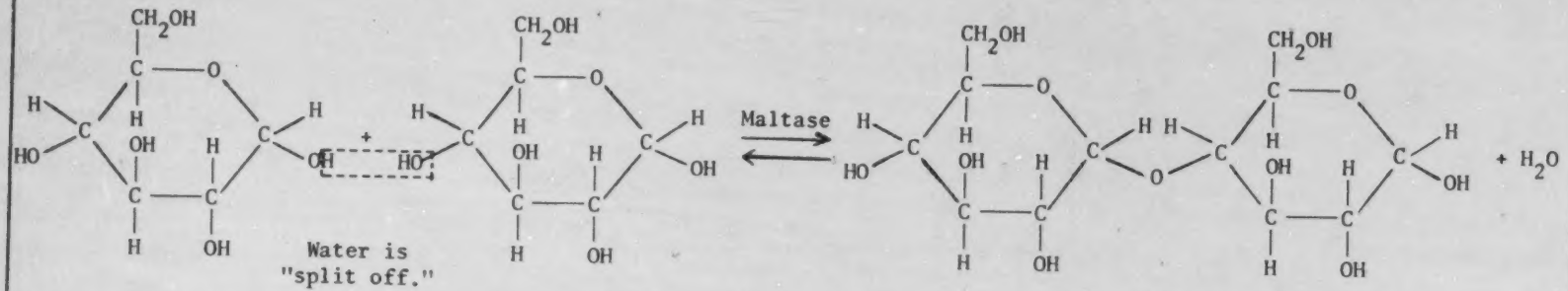
At relatively high temperatures, however, the "shape" of enzyme molecules tends to be altered, thus rendering the enzyme ineffective. This distortion of enzyme molecules at high temperatures is known as enzyme deactivation. For many enzymes deactivation occurs at around 40° C.

The response to changing temperatures for many enzymes is illustrated in the graph below:



Topics	Understandings and Fundamental Concepts	Supplementary Information
(3) Relative amounts of enzyme and substrate	The rate of enzyme action also varies according to the amount of available substrate molecules. When an excess of enzyme is added to a system with a fixed concentration of substrate, the rate of enzyme action tends to increase to a point and then remain fixed as long as the substrate concentration remains constant. The graph below illustrates the pattern of enzyme action rates when an excess of enzyme is added to a system with a fixed substrate concentration:  Enzyme Concentration (Substrate Concentration Constant) Conversely, if the level of enzyme concentration is constant, the rate of enzyme action will increase as substrate is added to the system but will stabilize at the point where all available enzyme molecules are actively involved in the reaction.	
2. Reactions	Although there are countless reactions taking place in cells at all times, hydrolysis and dehydration synthesis account for much of the biochemical activity in living systems.	Other reactions, including cellular respiration, photosynthesis and protein synthesis, are described in other units.
a. Dehydration synthesis	Dehydration synthesis is the process by which large organic molecules are built up from their building blocks with the release of water molecules.	Indicate that both dehydration synthesis and hydrolysis are enzyme-controlled, reversible reactions.

Topics	Understandings and Fundamental Concepts	Supplementary Information
b. Hydrolysis	Hydrolysis is the process by which these same molecules are broken down into their building blocks with the addition of water molecules. Below is an example of the dehydration synthesis - hydrolysis reactions associated with glucose and maltose.	Use of models, e.g.,"ball and stick" and styrofoam, will help students see the significance of these complementary reactions.



Unit 2 - Maintenance in Animals

The following statements provide a frame of reference for Unit II:

- *The animal examples used are treated horizontally with each life function being treated once for each representative organism.*
- *Evolutionary trends evident in comparing each representative are stressed.*
- *Emphasis is placed on the relationship between structure and function.*
- *Chemical concepts are treated descriptively and are introduced at points appropriate to the understanding of biological principles.*

Topics	Understandings and Fundamental Concepts	Supplementary Information
	The maintenance of animal life is dependent on universal requirements: . obtaining and distributing essential organic and inorganic compounds . removal of metabolic waste products . regulation of processes	
I. Nutrition		
A. Process	Nutrition includes those activities of animals by which they obtain and utilize various substances (known as nutrients or foods) for metabolic activity. Foods or nutrients are those substances that serve as: . energy sources for various life activities of cells . constituents in the building or repair of cell structures . regulators of metabolic processes Animals lack the ability to synthesize nutrients from inorganic raw materials and must consume preformed organic compounds. This mode of nutrition is known as heterotrophic nutrition.	While nutrition may be extended to include all activities and destinies of consumed materials, only intake and processing of nutrients are treated in this section. The distribution and specific roles of physiological compounds are described in later sections.

Topics	Understandings and Fundamental Concepts	Supplementary Information
	Usually, other organisms (plants and/or animals) are consumed by animals and serve as a source of preformed nutrients. Food organisms may contain unnecessary or unavailable compounds as well as those with nutritional value.	
1. Ingestion	Ingestion describes those activities of animals by which they take in materials (compounds and/or organisms) which serve as a basis for nutrition.	
2. Digestion	Digestion involves the reduction of large or insoluble food materials to small, soluble molecules which may be distributed throughout an animal and used for various physiological activities.	
	Digestion may occur within cells (intracellular) or outside of cells (extracellular).	
a. Mechanical aspects	Many animals exhibit adaptations which permit the breakdown of food materials to small particles through purely physical means such as grinding, cutting, and tearing.	
b. Chemical aspects	Mechanical digestion reduces food materials to particles which, by molecular standards, are still exceedingly large. Further reduction to soluble form is accomplished through the action of enzymes.	
(1) Enzyme action	Enzymes are proteins which act as catalysts and affect many physiological reactions, including digestion.	Teachers who do not select the BC extension of Unit 1 may wish to examine section C of the BC extension for additional treatment of enzymes.
	Digestive enzymes are hydrolytic. They promote the breakdown of large molecules to small unit molecules with the addition of water.	
	The name of an enzyme is usually formed by adding the ending *-ase* to a stem which is taken from the substrate, (compound, or class of compound), upon which the enzyme acts. Some examples of digestive enzymes and their substrates include:	

Topics	Understandings and Fundamental Concepts	Supplementary Information

Enzyme	Substrate
maltase	maltose
lipase	lipids
protease	protein

Enzymes are specific in their action. They will usually only catalyze reactions involving a single substrate compound or a group of closely-related compounds.

Temperature and hydrogen-ion concentration (pH) are two of the factors which determine the rate of enzyme action.

(2) Outcome — As a result of the action of enzymes in chemical digestion, complex organic molecules are hydrolyzed to smaller, soluble molecules.

- carbohydrates (sugars, starches, etc.) are converted to simple sugars such as glucose
- proteins are converted to amino acids
- lipids (fats, oils, etc.) are converted to fatty acids and glycerol

B. Adaptations — Nutritional patterns among animals vary in accordance with the adaptations which have evolved to permit the ingestion and digestion of food materials.

1. Protozoa — Protozoa ingest food organisms by taking them in through fixed openings (as in Paramecium) or engulfing them (as in Ameba).

Protozoa have no digestive tract. Ingested food materials accumulate in food vacuoles where digestion occurs. Digestion is intracellular.

Although Protozoa are classified by many biologists as Protists (see Unit VI, section C - A Modern Classification System), they are compared with animals in this section because they exhibit animal-like characteristics and are thought to be descendants of evolutionary precursors to multicellular animals.

Topics	Understandings and Fundamental Concepts	Supplementary Information
2. Hydra	Hydra possesses a digestive cavity with a single opening. The opening functions as a mouth for the ingestion of food and also as an anus for the expulsion of undigested and indigestible materials. Digestion begins in the cavity (extracellular digestion) where enzymes, secreted from specialized cells of the inner lining, partially hydrolyze the ingested food. Many of the remaining fragments are engulfed and digested by other cells of the inner lining (intracellular digestion).	Emphasize that, since almost all of the cells of the Hydra are in direct contact with the external environment, the genus has been able to survive without the evolution of methods of ingestion and digestion radically different from those of the Protozoa.
3. Earthworm	The digestive system consists of a tube within the body cavity with a mouth opening at one end and an anal opening at the other end. This one-way digestive tube permits specialized parts of the tube to perform sequential digestive functions.	Emphasize that, when a multicellular organism does not have most of its cells in direct contact with the external environment, specialized structures (organs) for the processing of food are essential to efficient function.
4. Grasshopper	In the grasshopper the structure and function of the digestive system are essentially similar to those in the earthworm.	
5. Man	In man the structure and function of the digestive system are basically like those of the earthworm and grasshopper.	

HP

C. Human digestion		
1. Digestive system	The human digestive system consists of a continuous tube, the alimentary canal, and the accessory organs which function in conjunction with the alimentary canal.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
a. The alimentary canal	The alimentary canal consists of the following, specialized subdivisions: . oral cavity . pharynx . esophagus . stomach . small intestine . large intestine	
b. Digestive glands	Digestive glands occur as specialized groups of cells lining the alimentary canal or in separate, accessory organs. Enzymes are secreted into the digestive tube where extracellular digestion occurs. . Glands within the digestive tube include the gastric glands of the stomach wall and the intestinal glands in the lining of the small intestine. . Accessory glands include the salivary glands, and the glands of the liver and pancreas. Secretions of these glands reach the digestive tube through ducts.	
2. Digestive function	Mechanical digestion results from the action of the teeth and tongue in the oral cavity and the muscular contractions (peristalsis) in the esophagus, stomach, and small intestine. Chemical digestion begins in the oral cavity and is completed in the small intestine. . Carbohydrate digestion begins in the oral cavity and is completed in the small intestine. . Protein digestion begins in the stomach and is completed in the small intestine. . Lipid digestion occurs in the small intestine.	Gastric enzymes function best in an acid (low pH) environment. Most digestive enzymes function best in a near-neutral (pH = 7) environment.

Topics	Understandings and Fundamental Concepts	Supplementary Information
	Undigested and indigestible materials accumulate in the large intestine where water is absorbed into the blood. The remaining materials form feces which are periodically evacuated through the anus.	
II. Transport		
A. Process		
1. Absorption	The end products of digestion, as well as other dissolved solids and gases, enter the fluids of animals through membranes.	
a. Structure of the cell membrane	The cell membrane selectively regulates the entry and exit of materials. This controlling influence of cell membranes aids cells in maintaining homeostasis.	
	The cell membrane is a complex, porous structure composed mainly of protein and lipid materials.	Evidence indicates that the lipid material is sandwiched between layers of protein.
	Dissolved solids (i.e., glucose), gases, ions, and water molecules diffuse through the cell membrane. Large molecules such as proteins, fats, and starch cannot diffuse into or out of cells.	Size does not seem to be the determining factor in all cases.
b. Function of the cell membrane	The cell membrane has both passive and active roles in transporting materials into and out of cells.	
(1) Passive transport	Some materials enter and leave cells by diffusing through the cell membrane. Diffusion is a form of transport in which cells do not contribute energy for the movement of materials.	In diffusion, movement is the result of the kinetic (heat) energy of a system of particles in motion.
	Diffusion is the process in which ions and soluble molecules move from a region where they occur in higher concentration to a region of lower concentration of the molecules or ions. The diffusion of water into and out of cells is called osmosis.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
(2) Active transport and pinocytosis	Active transport and pinocytosis are types of transport which require the expenditure of cellular energy.	
	Active transport is the process in which cellular energy is used to move molecules across membranes against a concentration gradient (i.e., from a region of lower concentration to a region of higher concentration).	
	Pinocytosis is a process in which large molecules or molecular aggregates that are too large to pass through the cell membrane may be engulfed and brought within the cell. Pinocytosis also requires the expenditure of cellular energy.	The term phagocytosis is usually reserved to describe the intake of larger particles. See section C, 2, b, (2) in HP extension of Transport.
2. Circulation	Circulation is the transport of materials within cells and/or throughout multicellular organisms.	
B. Adaptations	Animals have a variety of adaptations for the absorption and circulation of materials.	
1. Protozoa	Protozoa typically live in water, a transport medium. Absorption occurs between the environment and the cell contents.	
	Circulation within cells is accomplished by diffusion and by cytoplasmic streaming (cyclosis).	
2. Hydra	Since most of its cells are in direct contact with a watery environment, the Hydra has no special transport system.	
	The processes involved in transport in the Hydra are similar to that of Protozoa - diffusion, osmosis, cyclosis, and active transport.	
3. Earthworm	Many cells of the earthworm are not in direct contact with the external environment. An internal, closed circulatory system has evolved which indirectly brings materials from the external environment into contact with all cells. This system transports respiratory gases, water, and dissolved solids, including the end products of digestion.	An infolding of the earthworm's digestive tube is an adaptation which increases the absorptive surface through which digestive end products enter the blood.

Topics	Understandings and Fundamental Concepts	Supplementary Information
4. Grasshopper	The grasshopper has an internal, open circulatory system which indirectly brings materials from the external environment into contact with its cells.	Like the earthworm, the grasshopper has an infolded digestive tube to increase absorptive area.
5. Man	The closed circulatory system of man is similar in basic structure and function to that of the earthworm.	Man also has an adaptation for increasing absorptive area in the digestive tube.
UP		
C. Human circulation		
1. Circulatory system		
a. Structures		
(1) Heart	The human heart is a pumping device which consists of four chambers - two collecting chambers, the atria, and two pumping chambers, the ventricles.	
(2) Arteries	Arteries are relatively thick-walled, muscular vessels which transport blood from the heart to parts of the body. Most arteries lack valves.	
(3) Capillaries	Capillaries are blood vessels with walls only one cell thick. This feature permits ready exchange of materials between the blood and cells adjacent to the capillaries. Intercellular fluid (ICF), which surrounds all body cells, permits transport of materials to and from cells which are remote from capillaries.	
(4) Veins	Veins are relatively thin-walled vessels which transport blood from capillary beds back toward the heart. Many veins contain valves which prevent back-flow of blood in the system.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
(5) Lymph vessels	Lymph vessels make up a system of tubes which are essentially independent of the blood transport system. Lymph vessels transport lymph.	The lymph and blood systems connect at two points where lymph empties into the blood.
b. Fluids		
(1) Blood	Blood consists of a fluid (plasma) in which are suspended red and white blood cells and platelets. The plasma contains water, ions, and dissolved or suspended compounds including blood proteins, gases, and digestive end products.	
(2) Lymph	All cells of the body are bathed in a watery fluid (ICF) which originates from blood plasma and diffuses through capillary walls into surrounding tissues. Known as lymph when it is absorbed into lymph vessels, the intercellular fluid consists mostly of water and small amounts of proteins, salts, and so forth.	
2. Circulatory function		
a. Transport	The principal function of the human circulatory system is transport of dissolved and suspended materials throughout the body.	
b. Protection	The circulatory system contains mechanisms which have a protective function, including protection from blood loss through injury and from the harmful effects of disease-causing organisms (pathogens).	
(1) Clotting	The clotting of blood is an example of an enzyme-controlled activity. A clot forms when fibrin, a protein material consisting of long fibrous strands, is synthesized. The synthesis of fibrin results from enzyme-regulated reactions among disintegrated blood platelets, blood proteins, and calcium ions in the plasma.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	Fibrin tends to trap blood cells and fluid, and forms a mat-like mass which prevents blood loss from a wound.	
(2) Phagocytosis	Some white blood cells exhibit the property of engulfing bacteria and other pathogens. Such cells are known as phagocytes ("eating cells") and their action is known as phagocytosis.	
(3) Immunological reactions	Certain blood proteins belong to the class of compounds known as antibodies. Antibodies are synthesized when foreign proteins (antigens) are introduced into the blood. Antigen-antibody reactions tend to destroy, or neutralize, the harmful effects of antigens.	The immunization against diseases and the study of human blood groups are subjects which may be used to develop antigen-antibody concepts.
III. Respiration		
A. Process		
1. Cellular level	Cellular respiration occurs continuously in the cells of all animals. Most animals make energy available for cell activity by converting the potential energy or organic molecules (such as glucose) to the more available form of the high-energy compound adenosine triphosphate (ATP). ATP synthesis may employ free oxygen (aerobic respiration) or it may not (anaerobic respiration).	
a. Aerobic respiration	Most of the enzymes involved in cellular respiration are located in the mitochondria.	
(1) Description	During aerobic respiration, the energy of a compound such as glucose is released in small increments by the action of enzymes in removing hydrogen (removal of hydrogen from molecules is known as oxidation) from the molecule. The energy released is used to synthesize ATP.	

Topics	Understandings and Fundamental Concepts	Supplementary Information

The released hydrogen combines with oxygen to form water. (Oxygen serves as a hydrogen acceptor.) The remnants of the original glucose molecule are reorganized to form carbon dioxide.

The overall summary equation for aerobic respiration of glucose is:

$$\text{glucose} + \text{oxygen} \xrightarrow[\text{enzymes}]{\text{numerous}} \text{water} + \text{carbon dioxide} + 38\ \text{ATP's}$$

The energy of the ATP molecules is available for cellular activity and is released through the action of the enzyme ATP-ase.

BC

(2) Chemical aspects

Investigation of the chemistry of glucose oxidation has shown that the process, although involving many enzyme-catalyzed steps, occurs in two basic stages - the anaerobic phase and the aerobic phase.

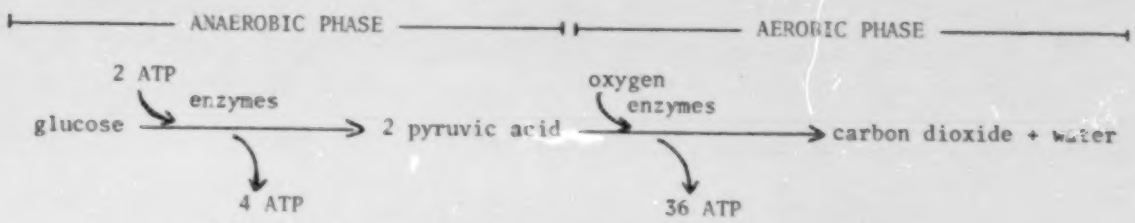
During the anaerobic phase, which does not involve molecular oxygen, glucose is converted to two molecules of pyruvic acid, and the released energy is used to synthesize 4 ATP molecules. However, since the energy of 2 ATP's is necessary to activate the reactions, there is a net gain of only 2 ATP molecules during the anaerobic phase.

The reactions of the aerobic phase continue the process of energy release by breaking the pyruvic acid down, eventually forming carbon dioxide. During this process, 36 ATP molecules are synthesized.

The net gain from the aerobic respiration of glucose is, therefore, 38 molecules of ATP.

Topics	Understandings and Fundamental Concepts	Supplementary Information

The relationships described on the previous page may be summarized as follows:



Energy relationships may be summarized as follows:

4 ATP	(from anaerobic phase)
+ 36 ATP	(from aerobic phase)
40 ATP	
- 2 ATP	(to activate anaerobic phase)
38 ATP	(net gain from oxidation of one glucose molecule)

b. Anaerobic respiration

Almost all animals carry on aerobic respiration. However certain animal cells respire anaerobically when oxygen is deficient or absent.

(1) Description

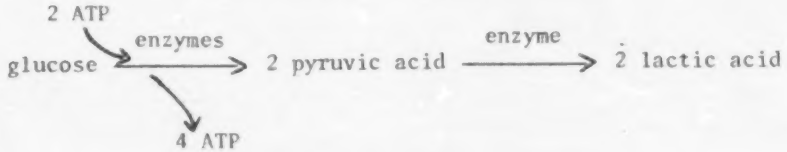
When it occurs in animals, anaerobic respiration leads to the formation of lactic acid and a relatively small amount of ATP.

Lactic acid production may be summarized as follows:

$$\text{glucose} \xrightarrow{\text{enzymes}} 2 \text{ lactic acid} + 2 \text{ ATP}$$

Lactic acid still contains much unreleased potential energy and the net gain of ATP is 2 molecules. This is a considerably less efficient energy-releasing system than the aerobic respiration of glucose.

Vigorous activity of human voluntary muscles may produce an oxygen deficiency which leads to a certain amount of anaerobic respiration and the accumulation of lactic acid in the cells. Lactic acid build-up is associated with fatigue.

Topics		Understandings and Fundamental Concepts	Supplementary Information
BC	(2) Chemical aspects	The formation of ATP in lactic acid production results from the same anaerobic reactions which occur in the anaerobic phase of aerobic respiration. There is no energy yield in the conversion of pyruvic acid to lactic acid. The reactions may be summarized as follows:  Deducting the 2 ATP's necessary for the activation of the process yields a net gain of 2 ATP's from the reactions which lead to the synthesis of lactic acid.	
	2. Organism level	Since anaerobic respiration is rare among animals, most respiratory activity requires oxygen and is essentially the same in all animal cells. The major differences in overall respiratory activity among different animals is in the manner in which they acquire oxygen for respiration and the method used to remove the carbon dioxide resulting from respiratory activity.	
	B. Adaptations	Animals have a variety of adaptations for the exchange of respiratory gases with their environment.	
	1. Protozoa	In protozoa, respiratory gases are exchanged directly with the watery environment by absorption through the cell membrane.	
	2. Hydra	The hydra, like the protozoa, is completely surrounded by water. Gas exchange occurs directly with the environment by absorption.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
3. Earthworm	In the earthworm, mucus secreted by cells of the external body wall provides a moist surface for gas exchange with the environment. The circulatory system transports respiratory gases to and from the moist skin.	
4. Grasshopper	The grasshopper has evolved an independent system of respiratory tubules for the intake, distribution, and removal of respiratory gases. The tracheal tubules are greatly branched. Their endings are intimately associated with moist internal tissues where gas exchange takes place.	
5. Man	Both man and the grasshopper have evolved a separate system of respiratory tubes. In man these are also greatly branched and extend throughout specialized gas exchange organs called lungs. The lungs also contain arteries, arterioles, veins, venules, and capillaries of the circulatory system. Gas exchange occurs between the respiratory tubules and the capillaries.	

HP

C. Human respiration

1. Respiratory system	The lungs are the principal respiratory organs in man. A system of passageways permit atmospheric air to enter and leave the lungs as the result of rhythmic contractions of the diaphragm and the muscles of the rib cage. The air passageways include the oral cavity, nasal passages, pharynx, larynx, trachea, bronchi, bronchial tubes, and alveoli.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
2. Respiratory function	In the alveoli some of the oxygen from the air diffuses into the blood, as carbon dioxide diffuses into the air space. Capillaries which surround the alveoli permit this gas exchange which is referred to as external respiration.	
	Breathing, the alternate expansion and contraction of the lungs, serves to replenish oxygen-rich atmospheric air in the alveoli.	The breathing rate is controlled by the nervous system and varies with the concentration of carbon dioxide in the blood.
	The transfer of oxygen and carbon dioxide between capillaries and body cells is referred to as internal respiration.	
	Cellular respiration is a complex process involving the energy transfer required for maintaining life.	
IV. Excretion		
A. Process	The metabolic wastes of animals include water, carbon dioxide, mineral salts, and nitrogenous wastes.	
	The metabolic activities which produce these wastes include:	

Metabolic activity	Waste(s) produced
Respiration	carbon dioxide and water
All metabolic processes	mineral salts
Dehydration synthesis	water
Protein metabolism	nitrogenous wastes

See section V on page 34 for details of dehydration synthesis.

B. Adaptations	Animals have a variety of adaptations for the disposal of harmful metabolic wastes.	
1. Protozoa	In Protozoa, carbon dioxide and mineral salts diffuse directly into the watery environment.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	Since protozoa are surrounded by fresh water, removal of water occurs against a concentration gradient. Active transport, including the "pumping" action of contractile vacuoles, serves in the excretion of excess water.	
	Nitrogenous waste, in the form of ammonia (which is very soluble in water) diffuses through the cell membrane.	
2. Hydra	Excretion in the hydra is essentially similar to that of protozoa.	
3. Earthworm	Carbon dioxide is excreted by diffusion through the moist skin of the earthworm.	
	Water, mineral salts, and nitrogenous wastes (in the form of ammonia and urea) are excreted by the action of paired nephridia located in each body segment.	
4. Grasshopper	Carbon dioxide diffuses from the grasshopper's blood into tracheae where it is transported to the atmosphere.	
	Water, mineral salts, and nitrogenous wastes (in the form of uric acid) accumulate in excretory tubules (Malpighian tubules) and are transported to the digestive tube. Most of the water is reabsorbed. Minerals and uric acid are expelled along with fecal material.	The excretion of solid waste (uric acid) is a water-conserving mechanism of particular advantage in a dry environment.
5. Man	Carbon dioxide is excreted by the action of the lungs.	
	The principal nitrogenous waste in man is urea. Urea, water, and mineral salts are removed from the blood in the nephrons of the kidneys. A system of tubes transports these wastes out of the body.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
HP		
C. Human excretion		
1. Excretory system	The organs of the human excretory system include the lungs, liver, skin, and kidneys.	
2. Excretory function		
a. Lungs	The diffusion of carbon dioxide into the alveoli of the lungs is the principal means of carbon dioxide excretion in man. In addition, water, in the form of vapor, is excreted in exhaled air.	
b. Liver	The breakdown of blood cells and other materials results in a large amount of urea synthesis in the liver. The urea is absorbed into the blood and transported to the kidneys. Bile salts are discharged into the small intestine from where they move to the large intestine for egestion with fecal material.	
c. Skin	The sweat glands of the skin permit the excretion of water and dissolved salts onto the surface of the skin. Water evaporates and salt crystals are removed by physical contact with clothing and other surfaces.	Perspiration, in addition to serving as an excretory fluid, is a major temperature-regulating device. Evaporation of perspiration utilizes heat from skin cells, thus lowering their temperature.
d. Kidney	The functional unit of the human kidney is the nephron. The nephron consists of a long, coiled tubule with a cup-shaped capsule at one end. Capillary beds within the capsules discharge water, salts, urea, amino acids, and glucose into the nephron. As these materials move through the tubule of the nephron, water, minerals, and digestive end-products are reabsorbed by active transport into capillaries associated with the tubule.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	After reabsorption, the fluid that remains consists mostly of water, urea, and salts, and is known as urine. Urine flows from the kidney through the ureter to the bladder. Periodically, urine is discharged from the bladder through the urethra.	
V. Synthesis		
A. Process	All animals, after processing ingested materials, use the resultant simple compounds for the synthesis of the thousands of compounds needed for maintenance.	
	Synthesis activities are many and varied. However, one common synthetic mechanism is known as dehydration synthesis. In this activity, simple unit molecules, such as glucose or amino acids, are incorporated into complex molecules made up of large numbers of unit molecules. In the process water is released.	The complementary relationship between dehydration synthesis and hydrolysis (see section I, A, 2, b, (1), in this unit) should be stressed.
	Dehydration synthesis accounts for the synthesis of glycogen from glucose and proteins from amino acids.	Glycogen, also known as animal starch, is a carbohydrate which resembles the starch which plants produce.
B. Products		
1. Secretions	Although synthesis occurs in all cells, certain substances, which are synthesized in abundance and have special roles in metabolism, are known as secretions. These are often the result of activity in specialized cells or tissues.	
	Among the most abundant secretions are enzymes, hormones, and neurohumors.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
a. Enzymes	Enzymes are proteins which catalyze virtually all reactions occurring in cells. Since the relationship between enzymes and the reactions they catalyze is highly specific, thousands of different enzymes are synthesized.	
b. Hormones	Hormones are compounds which vary considerably in their chemical properties. In general, they regulate a wide variety of physiological processes by accelerating or retarding activity.	
c. Neuro-humors	Neurohumors function in much the same manner as hormones. However, they are secreted by nerve cells.	
d. Other	In addition to the secretions mentioned on the previous page, animals produce a wide variety of other specialized secretions. Examples include: . hydrochloric acid of the human gastric glands . poisons secreted by various animals . mucus . human lachrymal fluid (tears) . waxes and oils	
2. Structural compounds	All of the structural components of cells result from the organization of synthesized materials into special, fixed relationships. Example: protein and lipid organization in membranes.	
C. Outcome	The results of synthesis activity are many and varied. Growth and repair of structures are two of the important results. In addition, the production of food reserves is a result of synthetic activity. Fat and glycogen are the most common storage products in animals.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
D. Human synthesis	Synthesis occurs throughout the entire body. As a result, there is no "synthesis system," as such.	
1. Limitations	Humans produce enzymes which permit the synthesis of most of the compounds necessary for normal physiological activity. However, man cannot synthesize some substances from available raw materials. These include certain amino acids and vitamins.	
2. Synthesis in relation to diet	The amino acids and vitamins man cannot synthesize are synthesized by a wide variety of plants and other animals. Since a well-balanced diet will include necessary substances, food supplements are rarely necessary.	
VI. Regulation		
A. Process	Organisms receive information from their environment and may respond to it by a movement, a secretion, or growth. In most animals regulation is achieved by the interaction of a nervous system and a system of specialized secretions.	
1. Nervous control		
a. Stimulus and response	A stimulus is a change in the environment that brings about a response. Stimuli may be external or internal. Responses are the reactions of organisms to stimuli.	

Topics	Understandings and Fundamental Concepts
	In most complex animals a system of specialized cells (neurons) reacts to stimuli from the environment. Stimuli initiate electrochemical impulses which are transmitted to the site of a response by a system of neurons.
b. Transmission of nerve impulses	Nerve impulses are transmitted through a system comprising neurons, synapses, and neurohumors.
(1) Neurons	Neurons are specialized cells which may be greatly elongated, thus providing rapid transmission of impulses over long distances.
(2) Synapses	Synapses are junction spaces between adjacent neurons.
(3) Neurohumors	Neurohumors are secreted by the ends of neurons and permit impulses to cross synapses by stimulating impulse production at the beginning of adjacent neurons.
2. Endocrine control	Regulation of many animal functions is accomplished by means of hormones. Glands which secrete hormones discharge their secretions directly into the circulatory fluid and are called endocrine or ductless glands.
a. Hormones	Hormones are sometimes called "chemical messengers." They are secreted by specialized cells and control the activities of other cells.
b. Effects	Hormones affect many activities in animals including: . growth patterns and rates . metamorphosis in some animals . periodic behavior, e.g. mating activity

Topics	Understandings and Fundamental Concepts	Supplementary Information
3. Comparison of nervous and endocrine systems	The nervous and endocrine systems show certain similarities and certain differences. Two similarities are: . Both play a major role in maintaining homeostasis . Both secrete chemical messengers Three differences are: . Nerve responses are more rapid than endocrine responses. . Nerve responses are of shorter duration than endocrine responses. . Nerve impulses travel by way of neurons while hormones are carried by the transport system.	
B. Adaptations		
1. Nervous systems	Animals have evolved a multiplicity of adaptations which tend to improve their ability to respond to stimuli.	
a. Protozoa	Protozoa exhibit regulated activity in response to environmental stimuli.	It is not clear how behavioral control is accomplished in Protozoa.
b. Hydra	The nervous system of the Hydra comprises a nerve net consisting of modified neurons in which impulses may travel in either direction. Since there is no central nervous system, impulses in the Hydra do not travel over definite pathways.	
c. Earthworm	The nervous system of the earthworm consists of a relatively simple anterior "brain" (fused ganglia), a ventral nerve cord, and connecting nerves. The presence of a central nervous system permits impulses to take a definite pathway from receptors to effectors.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
d. Grasshopper	The structure and function of the grasshopper's nervous system is similar to the nervous system of the earthworm.	
e. Man	The nervous system of man, composed of a brain, dorsal nerve cord and nerves, consists of two major functional divisions: . The central nervous system is involved with both voluntary and involuntary behavior. . The autonomic nervous system is a mutually antagonistic system of checks and balances which controls the involuntary responses of many internal organs, such as the heart, stomach, and intestines.	
2. Endocrine systems	A basic survey of endocrine systems will not show strong evolutionary patterns among representative animals. Some generalizations are possible: . In simple multicellular animals, discrete endocrine glands are not common. Hormonal secretion may occur in widely-dispersed cells. . Many hormones have wide distribution among animals, the same hormones occurring in both simple and highly complex animals.	This situation may be related to Unit VI - section I, C (Comparative biochemistry as evidence for evolution).

HP		
C. Human nervous regulation		
1. Nervous system	The behavior of man is dependent upon, and integral with, his complex nervous system.	
a. Structural units	The varied nerve aggregations comprise differing organizations of three basic neuron types.	
(1) Sensory neurons	Sensory neurons transmit impulses from sense organs (receptors) to the central nervous system.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	Sense organs, where major concentration of sensory neurons occur, include the eyes, ears, tongue, nasal passages, and skin.	
(2) Associative neurons	Associative neurons serve to interpret stimuli, to originate impulses to motor neurons, and to relay impulses between sensory and motor neurons.	
(3) Motor neurons	Motor neurons transmit impulses from the central nervous system to effectors (muscles and glands).	
b. Organization	The nervous system consists of several different organizations of neurons which are distinguishable on the basis of structure and function.	
(1) Nerves	Nerves are bundles of neurons, (sensory, motor, or both) which are specialized for the transmission of impulses over long distances.	
(2) Ganglia and plexuses	Ganglia are enlarged structures which contain associative neurons and serve as relay centers, redirecting incoming impulses toward nerve centers or effectors. Plexuses resemble ganglia in their function but are larger, sheet-like masses of nervous tissue.	
(3) Spinal cord	The spinal cord with its spinal nerves is an extension of the brain. It has coordinating functions, is a center for many reflex actions, and serves to conduct impulses between the brain and other body structures.	
(4) Brain	The brain is a large mass of neurons organized in three major divisions, each with specialized functions.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
(a) Cerebrum	In the cerebrum, sensory impulses become sensations, motor activities frequently are initiated, and conscious acts have their origin. The cerebrum functions as a memory bank and an integration center capable of creative thought.	
(b) Cerebellum	In the cerebellum, motor patterns are coordinated so that the organisms respond in an integrated manner rather than with random movements.	
(c) Medulla	Nerve impulses controlling the involuntary body activities, such as breathing, heartbeat, blood pressure, movements of the digestive system, coughing, and sneezing, originate in the medulla.	
2. Nervous functions		
a. Involuntary behavior	Involuntary behavior is automatic and may be either inborn or acquired.	
(1) Reflexes	Reflex actions are inborn, automatic patterns of behavior which are important in controlling everyday vital functions. Reflex behavior involves a characteristic route (reflex arc) over which impulses travel. In a spinal reflex there is a pathway from (1) sense organ (receptor) to (2) sensory neuron to (3) associative neurons in the spinal cord to (4) motor neuron to (5) muscle or gland (effector).	
(2) Conditioned behavior	Conditioned behavior is automatic behavior which is acquired. Habits are a form of conditioned behavior which involve the repeated performance of an act. This establishes pathways of nerve impulse transmission which permit automatic responses.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
b. Voluntary behavior	Voluntary behavior involves the cerebrum of the brain. It incorporates memory of past experiences, association, and judgment. Voluntary behavior is better developed in man than in other animals.	
D. Human endocrine regulation		
1. Endocrine system	The endocrine system consists of the endocrine glands and their secretions. Endocrine glands include: the thyroid gland, parathyroid glands, adrenal glands, the pituitary gland, the pancreas, and the sex glands.	
2. Endocrine function		
a. Thyroid gland	The thyroid hormone, thyroxin, regulates the rate of oxidation in the body and is essential for normal mental and physical development.	
b. Para-thyroid glands	Parathormone, the secretion of the parathyroids, controls the metabolism of calcium which is necessary for nerve function, blood clotting, and proper growth of teeth and bones.	
c. Adrenal glands	The adrenal glands secrete a variety of hormones including adrenalin (epinephrine), cortisone, and cortin. Adrenalin regulates rate of heart beat, blood sugar levels, blood-clotting rate, and so forth. Cortisone is necessary for the healthy condition of cartilage in joints at the ends of bones. Cortin controls the levels of salts in blood, and the blood pressure.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
d. Pituitary gland	The pituitary gland secretes a variety of hormones, many of which influence the activity of other endocrine glands. Examples include: . ACTH which stimulates the adrenal glands to produce cortisone. . FSH which stimulates activity in the ovaries.	
e. Pancreas	Located in the pancreas are small groups of cells (the Islets of Langerhans) which secrete the hormones insulin and glucagon. Insulin regulates blood sugar levels by promoting the outflow of sugar from the blood, e.g., into the storage areas of the liver and muscle. Glucagon stimulates the discharge of sugar from the liver into the blood.	
f. Sex glands	Male sex glands, located in the testes, secrete testosterone, the hormone which influences male secondary sex characteristics. Female sex glands secrete estrogen and other hormones. Estrogen influences female secondary sex characteristics.	
VII. Locomotion		
A. Process	The ability to move from place to place has increased the possibility of animal survival. Locomotion offers a number of advantages including: . increased opportunities to procure food . ability to seek shelter . movement away from toxic wastes . escape from predators . increased likelihood of contact between individuals capable of mating with each other	

Topics	Understandings and Fundamental Concepts	Supplementary Information
B. Adaptations	Animals have a wide variety of locomotive adaptations which permit survival in their particular environments.	
1. Protozoa	The locomotive structures utilized by protozoa include cilia, flagella, and pseudopodia.	
2. Hydra	The hydra is essentially a sessile organism (i.e., it tends to remain in a fixed position much of the time). However, the presence of contractile fibers permits some motion including a type of somersaulting motion by which it changes position at times.	
3. Earthworm	Locomotion in the earthworm is accomplished through the action of muscles and bristles (setae). The setae produce temporary anchorage in soil as muscles produce alternating extension and contraction of the animal's body.	
4. Grasshopper	Locomotion in the grasshopper is accomplished by interacting muscles which operate chitinous appendages (legs and wings).	
5. Man	Locomotion in man is accomplished by the interaction of muscles which move the bones of the skeleton.	

HP

C. Human locomotion		
1. Locomotive system		
a. Bones	The human skeleton consists of bones of various sizes and shapes. The functions of these bones include: . support of body structures . serving as anchor sites for muscle action . serving as levers for body movement . serving as protection for delicate internal organs	

Topics	Understandings and Fundamental Concepts	Supplementary Information
b. Muscles	The voluntary muscles, which control movements of the skeleton, are of two types. Extensors serve to extend the limbs. Flexors act to return extended limbs closer to the body. Movements of the skeleton involve the coordinated interaction of flexors and extensors working in pairs. Other muscles, not involved in locomotion, include: . smooth muscles which function in involuntary muscle activity such as breathing, peristalsis, and so forth . cardiac tissue which is found in the heart and maintains its beating action	
c. Tendons	Tendons are composed of connective tissue and serve to join muscles to bones.	
d. Ligaments	Ligaments also consist of connective tissue and bind ends of bones together forming joints, such as those of the elbow or knee.	
2. Locomotive function	The interaction of paired muscles serves to move the long bones of the skeleton and produce locomotion. Coordination of the muscles and bones is achieved by the nervous system and permits walking, running, and so forth.	

Unit 3 - Maintenance in Plants

In this unit emphasis is placed on physiological functions as related to vascular plants. The bean plant may be used as a representative organism in the laboratory work associated with this unit.

Topics	Understandings and Fundamental Concepts	Supplementary Information
I. Nutrition		
A. Autotrophic nutrition	Autotrophs are organisms which are able to meet their nutritional needs by the manufacture of their own organic molecules from inorganic raw materials. Most autotrophs carry on photosynthesis, but a few employ chemosynthetic methods to make food from inorganic sources.	
1. Photosynthesis	Photosynthesis is a process in which light energy is converted into the chemical bond energy of organic compounds.	
a. Process	About 80 percent of the total photosynthesis on earth occurs in the waters, and most of this is carried on by unicellular algae. Photosynthesis is also carried on by multicellular green plants. The process is essentially the same in both.	
(1) Description	Carbon dioxide and water are chemically utilized inside chloroplasts to form simple sugar molecules (commonly glucose and oxygen). Light energy is required as an energy source in some stages of this complex process.	There is still much about the process of photosynthesis that is not known. However, in recent years, there has been a tremendous increase in knowledge concerning the chemical pathways involved. Refined techniques of chromatography and the use of radioactive isotopes have contributed significantly to this knowledge.

A simplified summary equation for photosynthesis is:

$$\text{water} + \text{carbon dioxide} \xrightarrow[\text{chlorophyl, enzymes}]{\text{energy}} \text{glucose} + \text{water} + \text{oxygen}$$

The glucose formed may be converted in the cell into other compounds such as fats, proteins, or starch; or it may be used as an energy source during cellular respiration.

Topics		Understandings and Fundamental Concepts	Supplementary Information
		The use of oxygen-18 ("Heavy oxygen") by scientists has shown that the oxygen evolved in this process comes from the water. Carbon-14 has been successfully used to trace the pathways of carbon fixation in green plants. Photosynthesis is the source of most of the oxygen in the air.	The rate of photosynthesis is affected by a number of factors including temperature, carbon dioxide concentration, wavelength of light, and availability of certain minerals.
BC	(2) Chemical aspects	Two major sets of reactions occur in photosynthesis: - Photochemical reactions (Light reactions) During the light reactions, the light energy absorbed by chlorophyll is used to "split" water molecules, releasing hydrogen atoms and oxygen gas. - Carbon fixation reactions (Dark reactions) In the second group of reactions, carbon dioxide molecules and hydrogen atoms participate in a series of chemical changes. These result in the formation of PGAL (phosphoglyceraldehyde) from which other compounds, including glucose, are synthesized. PGAL may be used in several ways: some is recycled to continue carbon fixation; some may be oxidized to provide energy for syntheses; and some may be used in the synthesis of carbohydrates, proteins, or fats.	The nature of the photochemical reactions is still under investigation. These reactions, though fairly well understood, are still under investigation.

Topics	Understandings and Fundamental Concepts	Supplementary Information
b. Site	The photosynthetic process usually takes place within the chloroplast of a plant cell.	In some algae, chlorophyl is not contained within a chloroplast.
	The chloroplast is a complex, highly organized plastid which contains the photosynthetic pigments of chlorophyl.	Several types of chlorophyl are found in leaves; of these, chlorophyl a and chlorophyl b are the most important.
	The chlorophyl traps certain wavelengths of light energy (usually sunlight) and converts this energy into chemical bond energy inside the cell.	
	Red light and blue light are highly effective. Chlorophyl reflects green light.	
	Higher multicellular green plants have specialized organs, the leaves, which are the principal sites of photosynthesis.	
	Two adaptations of leaves for food-making are the comparatively large surfaces, which enable reception of light energy, and openings in the leaf, known as stomates, which permit the diffusion of carbon dioxide, water vapor, and oxygen between the leaf and the atmosphere. The size of the stomates is controlled by guard cells.	
	The stomates open into air spaces that are in contact with an internal moist surface which aids the diffusion of carbon dioxide from the air into the cells.	
	Water for photosynthesis enters complex plants through the root hairs by osmosis and is conducted to the photosynthetic tissues through the vascular tissue.	Refer to section III (Transport) of this unit for further considerations of water transport.

Topics	Understandings and Fundamental Concepts	Supplementary Information
BC 2. Chemo-synthesis	Some bacteria are able to synthesize organic compounds from inorganic sources without a need for light energy. These bacteria oxidize compounds of nitrogen, sulfur, or iron, and are able to use the small quantity of energy released by the oxidation. This energy is then used to manufacture food. Example: The nitrifying bacteria, which oxidize ammonia and nitrites, play an important role in the nitrogen cycle.	See page 99 - The Nitrogen Cycle
B. Heterotrophic nutrition	Heterotrophic plants, such as fungi and most bacteria, lack chlorophyl and are unable to synthesize their own complex organic compounds from inorganic compounds. These organisms obtain performed organic molecules from other organisms by extracellular digestion and absorption. This method of energy capture is essentially the same as it is in animals.	Although bacteria, fungi, and algae are considered by many biologists as protists (see Unit VI, section C, Modern Classification System) they are considered with plants in this unit because they exhibit plant-like characteristics and are thought to be evolutionary precursors of multi-cellular plants.
II. Digestion	Plants lack a specialized digestive system, but the kinds of changes that occur in digestion are similar in all plants and animals. Plants store starches, lipids, or proteins in cells. These storage products are converted into the simpler usable forms as a result of enzymatic hydrolysis within the cells (intracellular digestion). Once digestion is completed, the end products may be used in the cell, or they may be transported to other tissues for use there. Heterotrophic plants secrete enzymes which hydrolyze foods outside the plant, changing them into simple organic compounds which can be absorbed and used for energy or converted into more complex compounds.	The principal carbohydrate reserve of higher plants is starch. It is stored in large amounts in seeds, stems, and roots. Insectivorous plants carry on extracellular digestion of insects.

Topics	Understandings and Fundamental Concepts	Supplementary Information
III. Transport	The process of material transport is similar in plants and animals.	Gas transport is considered under the topics of photosynthesis and respiration.
	Higher plants have specialized absorbing structures and transport (vascular) tissues to provide cells with required materials.	Like animals, complex plants have a transport system. Circulation in plants is referred to as translocation.
A. Roots	Roots and root hairs are structures specialized for anchorage and absorption.	
1. Root hairs	Root hairs are elongated epidermal cells which increase the surface area of the root for the absorption of water and minerals.	
	The movement of minerals and water from the soil into the plant is accomplished by active transport and diffusion processes.	
2. Xylem	Xylem and phloem are plant tissues specialized for transport. These tissues extend from the roots to the edges of the leaves.	
	The principal function of the xylem tissue is to conduct water and minerals upward in the plant.	
3. Phloem	Phloem conducts organic food materials both upward and downward to plant tissues for immediate use or storage.	
B. Stems	Although the anatomy of the stem differs from that of the roots, the conducting tissues of the stem (xylem and phloem) are continuous with those of the root.	Horizontal transport is also necessary in plants of large diameter, such as trees, if all cells are to receive nutrients. This is accomplished in vascular and pith rays by diffusion and active transport.

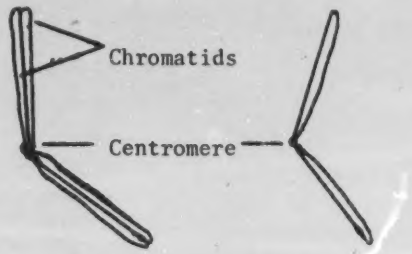
Topics	Understandings and Fundamental Concepts	Supplementary Information
	The physical factors concerned with upward transport in the xylem are transpiration pull, capillary action, and root pressure.	The factors affecting movement of materials in the phloem are not completely understood at this time.
C. Leaves	Leaves contain veins which are extensions of the xylem and phloem of the stem.	
IV. Respiration	In green plants, respiration occurs 24 hours a day as in animals. Photosynthesis occurs only when light energy is present.	
	The energy from solar radiation, captured by photosynthesis in the chemical bonds of organic molecules, is converted into ATP molecules during the process of respiration.	Some ATP is formed during photosynthesis, but this process is not considered as a net source of ATP production.
A. Types		
1. Aerobic	Aerobic respiration occurs in the presence of free (molecular) oxygen.	
	Oxygen and carbon dioxide move from areas of greater concentration to areas of lesser concentration by diffusion. Gases may enter or leave the large internal intercellular air spaces of the plant through the stomates and the lenticels of woody stems.	Roots will also function as respiratory organs if the soil is well aerated.
	As the free oxygen content increases in a cell during photosynthesis, the gas will diffuse into the air spaces and may escape into the atmosphere or diffuse into cells having an inadequate supply.	
	When photosynthesis is not occurring in the cells, oxygen may diffuse from the air spaces into the cells and from the atmosphere into the air spaces.	
	As in animals, the mitochondria are the sites of the chemical activities associated with energy conversion in respiration.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
a. Description	Many unicellular and multicellular plants release energy by aerobic respiration in a manner which is essentially the same as that in animals. See Unit II, Section III, A, 1, a, (1).	
BC b. Chemical aspects	See Unit II, Section III, A, 1, a, (2).	
2. Anaerobic	Anaerobic respiration does not require free oxygen.	
a. Description	Since molecular oxygen is not utilized in the release of energy from organic compounds in anaerobic respiration, it takes place whether or not oxygen is present. See Unit II, Section III, A, 1, b, (1). In the continued absence of oxygen, ethyl alcohol or lactic acid may be produced by a process called fermentation.	
BC b. Chemical aspects	Anaerobic respiration is similar in plants and animals.	
(1) Alcoholic fermentation	This process begins with the formation of pyruvic acid by the same sequence of enzyme-catalyzed steps that produced it in animal tissues. If molecular oxygen is lacking, some simple plants, such as certain bacteria and yeasts, carry on alcoholic fermentation, producing ethyl alcohol and carbon dioxide as products of the reaction. The organisms derive their energy from the glucose bonds.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	A simplified summary equation for the alcoholic fermentation of glucose is: Glucose ⟶ pyruvic acid ⟶ ethyl alcohol + carbon dioxide + energy	
	Most of the released energy is stored in ATP bonds. However, most of the potential energy of glucose still remains in the bonds of alcohol.	Alcohol fermentation has value in such industries as baking, brewing, and wine-making.
(2) Lactic acid fermentation	Lactic acid bacteria and certain molds can carry on lactic acid fermentation. In this process the bacteria or molds also obtain their energy from the bonds in glucose, and lactic acid in the product of the reaction.	Lactic acid fermentation has commercial value in the food, fermentation, pharmaceutical and chemical industries.
	See Unit II, Section III, A, 1, b, (1) and (2).	
B. Energy yield	Since most of the C-C and C-H bonds of the compound remain intact at the end of both alcoholic and lactic acid fermentations, only a relatively small amount of energy is released in comparison to the amount released in aerobic respiration.	
	Anaerobic respiration provides enough energy to support lower forms of life, such as bacteria and yeasts, whereas aerobic respiration provides the energy needed by higher plants.	Yeasts may also respire aerobically.
V. Excretion	Plants have no specialized system for excretion comparable to that of the higher animals.	
	Since green plants are able to use many of the products of metabolism in synthesis, they give off only those products which are no longer useful to them.	
	The main product of carbohydrate metabolism, carbon dioxide, is nontoxic to plants and can be reused in the photosynthetic process.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	Some of the oxygen produced in photosynthesis is used by the plant for respiration.	
	Excess carbon dioxide leaves the plant by diffusion through the stomates, lenticels, and roots.	
	Excess water moves as a vapor through the stomates and lenticels by the process of transpiration. Since most of this transpired water is not a metabolic waste, it is not a true excretory product.	
	Some products, such as organic acids, which might be toxic, are stored in vacuoles where they are "sealed off" and cause no injury to the plant.	
	Ordinarily, plants can use the ammonia and other nitrogen compounds derived from breakdown processes. These, along with additional absorbed nitrogen compounds, are used to synthesize amino acids and other compounds.	
VI. Synthesis		
A. Process	Synthesis in a plant cell involves the formation of complex, functional compounds necessary for the maintenance of that cell, or in multicellular plants for the survival of other cells in the plant.	
B. Products		
1. Structural	Both the production of new structures and the repair of existing structures in plant cells result from synthetic activities which form carbohydrates, fats, and proteins. The glucose molecule synthesized as a result of photosynthesis can, in turn, be used for the synthesis - by dehydration - of more complex carbohydrates such as starch.	
2. Other	A wide variety of chemical substances are synthesized by plants. These include: poisons, waxes, fibers, drugs, and flavorings.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
C. Outcome	In addition to growth and repair in the cell, synthetic products may also serve to resupply specific compounds required by individual cells or by the entire plant (e.g., starch).	The most abundant organic reserve is starch. Starch is insoluble or nearly so, and thus does not tend to affect the osmotic pressure in a cell.
	Auxins regulate plant growth, while scents and poisons are associated with reproduction and protection.	
VII. Regulation	Complex plants lack a nervous system, but have chemical regulators, the best known (and most common) of which are the auxins.	The most widely distributed auxin is known as IAA - indolacetic acid.
		Gibberellins represent another class of growth-regulating compounds.
A. Production of auxins	Auxins are a group of substances produced in the tips and roots, and subsequently transported to other parts of the plant. These function as plant growth regulators.	Auxins have been found to stimulate rapid growth in young stems and to induce the development of flowering in a number of plants.
B. Effects of auxins	Auxins are distributed throughout stems and roots, maintaining normal growth. Unequal distribution of auxins is brought about by stimuli such as light and gravity.	
	Differences in auxin distribution bring about growth responses called tropisms. These responses are effected by accelerating or retarding the lengthwise growth of individual cells.	
	Phototropism and geotropism are plant growth responses which may be explained in terms of unequal distribution of auxins.	
	Auxins also appear to have some affect on cell division and, as such, have commercial value as stimulators of rapid and extensive root formation on stem cuttings.	Auxins also play a role in leaf and fruit abscission.

Topics	Understandings and Fundamental Concepts	Supplementary Information
I. Cell Division	All cells arise from other cells by cell division. The process is complex and involves both nuclear and cytoplasmic division.	In unicellular organisms, the consequences of cell division may be considered reproduction; in multicellular organisms, cell division generally accounts for growth in size. Cancer may be considered a kind of abnormal cell division.
A. Mitotic cell division	Mitotic cell division usually involves two aspects: 1) MITOSIS - an orderly series of complex changes in the nucleus, normally resulting in a precise duplication of the chromosomes and the distribution of a complete set of chromosomes to each daughter cell. 2) CYTOPLASMIC DIVISION - division of the cytoplasm which may occur during or after mitosis.	
1. Processes		
a. Mitosis	The process of mitosis involves: . replication of each chromosome during the non-dividing period, resulting in double-stranded chromosomes. Individual strands are known as chromatids. . disintegration of the nuclear membrane during the early stages of division . synthesis of a spindle apparatus . attachment of double-stranded chromosomes to spindle fibers by centromeres . replication of centromeres, permitting separation of single-stranded chromosomes and their movement to opposite ends of the spindle	The immediate stimulus necessary to initiate mitosis is unknown.  Double-Stranded Chromosome Single-Stranded Chromosome

Topics	Understandings and Fundamental Concepts	Supplementary Information
	nuclear membrane formation around each set of newly formed chromosomes, restoring the non-dividing state of the nucleus (although the chromosomes are single-stranded at this point)	By means of visual aids, demonstrate the changes that occur in the nucleus during mitosis. The names of phases are helpful but not required for examination purposes.
	The major result of mitosis is the formation of two daughter nuclei which are identical to each other and to the original nucleus, in number and types of chromosomes.	
b. Cytoplasmic division	Division of the cytoplasm usually, but not always, accompanies mitosis.	
	In animal cells, division of the cytoplasm is accomplished by a furrowing of the cell, thus separating the two nuclei.	
	In plant cells, a cell plate, on which cell walls form, is synthesized, thus separating the newly formed nuclei.	
2. Comparison between plant and animal cell division	Mitosis is similar in plant and animal cells.	
	In most seed plants, the spindle apparatus appears to be synthesized directly by the cytoplasm without centrioles.	Centrioles have been detected in lower forms of plant life.
	The methods of cytoplasmic division differ in plant and animal cells.	
B. Meiotic cell division	Meiosis is a special form of *nuclear* division which is associated with sexual reproduction and the formation of monoploid gametes.	Discussion of meiosis in this unit is restricted to higher organisms.
1. Process	The process of meiosis involves: 1) First Meiotic Division . replication of each chromosome occurs early in the first meiotic division	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	. synapsis (intimate pairing) of homologous chromosomes. During synapsis, the chromosomes often twist about each other . alignment of homologous pairs on the spindle . disjunction of homologous pairs, one of each pair moving to opposite ends of the spindle	Homologous chromosomes are chromosomes that pair during meiosis. In diploid cells destined to produce gametes, the even number of chromosomes exist as homologous pairs. Nondisjunction and cross-over, both consequences of synaptic pairing, will be treated in Unit V.
	2) Second Meiotic Division . alignments of double-stranded chromosomes on spindle . replication of centromeres . migration of single-stranded chromosomes toward opposite ends of spindle	The distribution of homologues (members of a pair of homologous chromosomes) between the two resultant nuclei is random.
	As a result of meiosis, also known as reduction division, diploid (2n chromosome number) primary sex cells will become specialized reproductive cells with a monoploid (n) nucleus.	
2. Comparison with mitotic cell division	Mitosis is associated with growth and asexual reproduction; meiosis, with sex cell production. As a result of mitosis, daughter cells have the same chromosome complement as the original cell. As a result of meiosis, daughter cells have one-half the chromosome complement of the original cell.	
II. Reproduction		
A. Asexual	Asexual reproduction is any method of producing new organisms which does not involve fusion of nuclei. The new organisms develop from undifferentiated cells of the parent, essentially by mitotic cell division.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
1. Types	Many unicellular organisms reproduce asexually by fission or budding. Fission occurs with equal division of the cytoplasm. In budding, cytoplasmic division is unequal.	
	Budding may also occur in some multicellular animals.	
	There is evidence of mitotic cell division in most cases of fission or budding.	
	In many plants and some simple animals, single, specialized cells, known as spores, are released from the parent and can develop into new individuals.	
	Some multicellular plants reproduce asexually by vegetative propagation. The presence of undifferentiated tissue provides the source of cells from which new plants may develop from the parent by vegetative means.	Examples of vegetative propagation include: cuttings, bulbs, stolons, tubers, and corms.
	Generally, the invertebrate animals possess more undifferentiated cells than do the vertebrate animals. Thus, asexual reproduction is characteristic of many of the invertebrates.	
2. Results	Since undifferentiated cells are produced as a result of mitosis within the parent, the offspring are genetically like the parent, unless mutations occur in the cells destined to become new individuals.	
B. Sexual	The sexual reproductive cycle involves the production by adult organisms of functional sex cells (gametes), the fusion of the nuclei of sex cells at fertilization to form a zygote, and the development of the zygote which may develop to the adult stage, completing the cycle.	Consideration of sexual reproduction in this unit is limited to higher plants and animals.
1. Animals		

Topics	Understandings and Fundamental Concepts	Supplementary Information
a. Gamete formation	Male and female gametes are usually developed in specialized organs called gonads. Males possess testes, which produce the male gametes, sperms; females possess ovaries, which produce the female gametes, eggs. Organisms which contain functional male and female gonads are known as hermaphrodites.	Hydra and earthworm are examples of hermaphrodites.
(1) Male	Four monoploid sperms usually develop from each primary sex cell that undergoes meiosis in the testis.	
(2) Female	Only one monoploid egg cell is usually formed from each primary sex cell that undergoes meiosis in the ovary. The accessory cells, known as polar bodies, which result from meiotic divisions, may degenerate. At the beginning of the differentiation process of the egg, food (yolk) is deposited within the cytoplasm.	Meiotic divisions, in which the chromosome number is reduced from diploid to monoploid, are sometimes referred to as maturation divisions.
b. Zygote formation	Fertilization is the union of the egg nucleus, containing the n chromosome number, with the sperm nucleus, also containing the n chromosome number, to form a zygote containing the 2n chromosome number. Thus, the species number of chromosomes is restored and homologous pairs of chromosomes are reformed.	
	Parthenogenesis, the development of an egg without fertilization, is a modification of sexual reproduction.	Parthenogenesis may occur naturally as in the production of male bees. It has been achieved experimentally with the eggs of such animals as frogs, rabbits, and turkeys. Interpretations differ concerning parthenogenesis as a form of sexual reproduction, since it does not involve fertilization.

Topics	Understandings and Fundamental Concepts	Supplementary Information
(1) External fertilization	Reproduction in most vertebrate animals which reproduce in water is characterized by external fertilization, since the gametes fuse outside the body of the female.	
(2) Internal fertilization	Fertilization within the body of the female is characteristic of animals that reproduce on land. Internal fertilization provides a moist environment for the transport of motile sperms. The number of eggs produced is related to the following factors which affect the chances for survival: 1) type of fertilization - external or internal 2) type of early development - external or internal 3) amount of parental care Generally, animals that carry on external fertilization produce more eggs than animals that carry on internal fertilization. This is an advantage to the species since the chances for survival of externally fertilized eggs are not as great as those for the survival of internally fertilized eggs.	
c. Embryo formation	The zygote, or fertilized egg, immediately begins to go through a series of mitotic divisions, known as cleavage, which produces a multicellular embryo.	Cleavage is thought to be stimulated by fertilization. Factors initiating cleavage in cases of parthenogenesis are not fully understood.
2. Plants		
a. Gamete formation	The processes of meiosis and fertilization occur in the flower, a structure specialized for reproduction in higher plants.	Consideration of sexual reproduction in plants is limited to higher plants.

Topics	Understandings and Fundamental Concepts	Supplementary Information
	The flower may contain the male reproductive organ, the stamen, and the female reproductive organ, the pistil. In some species, certain flowers contain only stamens (male), while other flowers contain only pistils (female).	
(1) Male	The diploid cells of the anther, a part of the stamen, produce pollen grains which contain monoploid nuclei.	
(2) Female	The ovule developing within the ovary of the pistil, contains the monoploid egg nucleus.	
b. Zygote formation		
(1) Pollination	The transfer of pollen grains from the anther of the stamen to the stigma of the pistil is known as pollination. Pollination may be accomplished by wind, water, insects, and birds. Flowering plants often have the problem of sperm transfer in a dry, external environment. This is partially solved by the presence of the thick wall of the pollen grain which prevents dehydration of its contents during its transfer to the female reproductive organ. The pollen grain germinates on the stigma and forms a tube which extends into the ovule. Sperm nuclei are formed at this time in the pollen tube.	
(2) Fertilization	The union of male (n) and female (n) nuclei in the ovule results in a diploid (2n) nucleus which develops into a new plant.	In higher plants, the sperm and egg nuclei (although not cells) effectively function as gametes. The mechanism of double fertilization is not required for examination purposes.

Topics	Understandings and Fundamental Concepts	Supplementary Information
c. Embryo formation	Inside the ovule, the zygote undergoes a series of mitotic divisions which results in a multicellular embryo.	
RD III. Development	Development refers to the growth and change of the fertilized egg to the adult form. The process involves cleavage, differentiation, and growth.	Regeneration, the process of replacing lost parts in an organism after damage or removal, may be considered a form of development, since it does involve cell division, differentiation, and growth.
A. Animals		
1. Embryonic development		
a. Cleavage and differentiation	Cleavage leads to the formation of the blastula, a single layer of cells forming a hollow ball.	
	One side of the blastula becomes indented (gastrulation) forming the gastrula, a two-layered structure, having an inner layer, the endoderm, and an outer layer, the ectoderm.	
	As development continues, a third layer, the mesoderm, forms between the ectoderm and the endoderm.	
	These three embryonic layers differentiate and give rise to the various tissues, organs, and systems of the multicellular animal.	The precise mechanisms of the process of differentiation are still under study.
b. Site of embryonic development		

Topics	Understandings and Fundamental Concepts	Supplementary Information
(1) External	External development occurs outside of the female's body.	
(a) In water	The eggs of most fish and amphibians are fertilized externally and develop externally in a water environment. The developing embryo's source of food is the yolk stored in the egg.	
(b) On land	Eggs of birds, many reptiles, and a few mammals develop externally in a land environment after internal fertilization. The developing embryo's source of food is the yolk stored in the egg. Some adaptations for animals which develop externally on land are a shell which provides protection, and membranes which help provide a favorable environment for embryo development. These embryonic membranes include: . the chorion which lines the shell and surrounds the embryo and other membranes. It serves as a moist membrane for gaseous exchange. . the allantois which functions in respiration and excretion. . the amnion which encompasses the amniotic fluid. This fluid provides a water environment and protection from shock or adhesion to shell. . the yolk sac which surrounds the yolk. Blood vessels penetrating the yolk sac transport food to the developing animal.	
(2) Internal	Mammals employ internal fertilization and, typically, their embryos develop internally within a structure called the uterus.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	The egg has relatively little yolk and is very small. The food source will consist of the nutrients in the blood of the mother.	
(a) Placental animals	Some adaptations for animals which develop internally are highly complex and provide the protection, nutrients, and gas and liquid exchange that are essential to embryonic development. These adaptations include: . the amnion which encompasses the amniotic fluid. This fluid provides a water environment and protection against shock. . the placenta which is composed of tissues from both the embryo and the parent. It is the site of the transfer of oxygen, food, wastes, and other materials between the parent and the embryo. There is no direct connection between their bloodstreams; transport is accomplished by diffusion and active transport. . the umbilical cord which is the structural and functional attachment of the embryo to the placenta.	
(b) Non-placental animals	Pouched mammals, some fishes and some reptiles employ internal fertilization and internal embryo development without direct nourishment from the parent. The source of food is the yolk stored in the egg. Adaptations for the development of these embryos are the same as in birds, except that the shell is not calcareous.	
2. Post-embryonic development	The growth and change of the embryo to adult may be referred to as maturation. Post-embryonic development also involves cell multiplication and differentiation, but the most obvious changes involve increases in size. During this process most animals grow in various directions at once at different rates, giving each one its distinctive shape.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	The maturing process may be essentially uninterrupted, as in the case of mammals, or it may be interrupted, as in the case of Arthropods undergoing molting or metamorphosis. Differentiation is completed when all organs have reached adult form. Further cell division is then restricted to repair and replacement.	
B. Plants		
1. Seed formation	The plant embryo consists of the epicotyl, cotyledon(s), and the hypocotyl. The epicotyl develops into the leaves and upper portions of the stem; the cotyledon(s) store(s) food; the hypocotyl develops into the root and lower portion of the stem. The embryo is enclosed in seed coats which develop from the outer coverings of the ovule. The embryo and its coats are called a seed.	
2. Seed development	In flowering plants, seeds may develop inside a fruit. The fruit is one of the means of seed dispersal in plants. Under suitable environmental conditions, seeds will germinate, producing new plants. These conditions include: . sufficient moisture . proper temperature . sufficient oxygen The transformation of a seed into a mature plant, capable of reproduction, involves cell division, differentiation, and growth. Growth in higher plants is restricted largely to specific regions known as meristems.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	Apical meristems are found in the tips of roots and stems. A number of plants also contain an active lateral meristem region, commonly known as the cambium.	The cambium is not active in many herbaceous dicots. The cambium (actually the vascular cambium) should not be confused with another kind of lateral meristem - the cork cambium - present in most woody plants.
	These growth regions contain undifferentiated cells which are undergoing active cell reproduction. As a result of differentiation, various tissues are developed according to the pattern which is distinctive for each species of plant.	
	Apical meristems are concerned with growth in length. The cambium, located between the xylem and phloem, is responsible for the growth in diameter of roots and stems.	
	Plant growth changes include also the formation of leaves and floral parts.	
IV. Reproduction and Development in Man		
A. Reproduction		
1. Gamete formation		
a. Male reproductive system		
(1) Structure	Testes are paired structures which produce the male gametes, sperms; they are located in an outpocketing of the body wall known as the scrotum.	

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Topics	Understandings and Fundamental Concepts	Supplementary Information
	Scrotal temperature is 2-4 degrees lower than body temperature. This lower temperature is optimal for sperm production and storage. A series of ducts furnish a passageway for sperms from the testes to the outside of the body. Glands secrete a liquid into these ducts which serves as a transport medium for the sperm - an adaptation for life on land.	
(2) Function	In addition to producing sperms, the testes also produce male sex hormones. These regulate the development of secondary sex characteristics, such as beard development and voice quality.	
b. Female reproductive system		
(1) Structure	Ovaries are paired structures located in the lower portion of the abdominal cavity. Ovaries produce eggs by meiosis in tiny cavities called follicles. Egg cells leave the follicle of the ovary (ovulation) and are transported through the oviducts to the upper end of the uterus. At the lower end the uterus is connected to a muscular tube, the vagina. At birth, all of the eggs that a female will ovulate are present in the ovaries. Usually only one egg is released in ovulation during each cycle.	
(2) Function	In addition to eggs, the ovaries also produce female sex hormones. These regulate the development of secondary sex characteristics, such as the development of the mammary glands and the broadening of the pelvis, and they also play a part in the menstrual cycle.	

Topics		Understandings and Fundamental Concepts	Supplementary Information
	(a) Role of hormones	The reproductive cycle of the human female involves interaction of the pituitary gland, the ovary, and the uterus. Hormones from the pituitary gland control the functioning of the ovaries during this cycle. The ovaries, in turn, produce hormones which control the changes of the uterus. In addition, the hormones from the ovary control the production of hormones by the pituitary gland (feedback mechanism).	
	(b) Menstrual cycle	The menstrual cycle consists of four recognizable stages: . follicle stage . ovulation . corpus luteum stage . menstruation The last stage refers to the periodic shedding of the uterine lining which occurs when fertilization does not take place. The duration of each cycle is approximately 28 days. These cycles begin at puberty, are temporarily suspended during pregnancy, and end at menopause. The duration of the cycle may vary considerably from female to female and may be interrupted by illness.	
2. Zygote formation		Sperm and egg usually fuse in the upper portion of the oviduct. If more than one egg is released and fertilized, multiple births may result. Identical twins may develop from separated cells derived from the same zygote.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	If the egg is fertilized, cleavage begins in the oviduct, and 6 to 10 days later the resulting embryo may become implanted in the uterus. If the egg is not fertilized within approximately 24 hours after ovulation, it deteriorates and leaves the body with the menstrual discharge through the vagina.	
B. Development		
1. Prenatal	Embryonic development includes: . cleavage in the oviduct. At this time the number of cells increases without a corresponding increase in mass. . gastrulation, which occurs after implantation in the uterus . differentiation, or the formation of specialized tissues and organs from the embryonic layers: from the ectoderm - nervous system and epidermis of skin from the mesoderm - muscles, circulatory system, skeleton, excretory system, gonads, inner layer of skin from the endoderm - lining of digestive and respiratory tracts, portions of liver and pancreas . growth, an increase in cell number as well as in size of cells. Early growth consists chiefly of differentiation of cells and tissues. This is followed by changes in size and structure.	No organ in the body is derived exclusively from any one of the three primary germ layers.
	Birth usually occurs after a gestation period of nine months.	Gestation is the period of time between fertilization and birth in mammals.
2. Postnatal	Development continues with various parts of the body continuing to grow at differing rates until the adult state is reached.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	Human reproductive tissues undergo prolonged development. Puberty, the onset of reproductive capability, is regulated by the nervous and endocrine systems and generally occurs between the ages of 9 and 18. In time there is a deterioration of structure or function in the mature individual. This aspect of development is known as "aging," a result of the interplay of hereditary and environmental factors, which ultimately ends in death. The cause or causes of the degenerative changes which are characteristic of the aging process are still not fully understood.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
I. Mendelian Heredity	Genetics, the science of heredity, is based on the principles developed by Gregor Mendel. Using garden peas, Mendel made many crosses and charted the patterns of inheritance of plant characteristics from parents to offspring. Analysis of his data permitted Mendel to devise a hypothetical model of the pattern of heredity in the pea plant. The principles of *dominance*, *segregation*, and *independent assortment* were part of the contributions Mendel made to the understanding of the hereditary process.	It should be stressed that Mendel did not propose a mechanism to account for the hereditary patterns he observed.
A. Dominance	When pea plants having alternate forms of a contrasting character were crossed, the offspring resembled only one parent, the dominant one. The character which did not appear among the offspring was called the recessive character. Offspring of this type were designated as the F_1 generation.	
B. Segregation	When F_1 individuals were crossed (self-pollinated), the hidden recessive character segregated out and appeared in about one-quarter of the offspring. These offspring were designated as the F_2 generation.	
C. Independent assortment	In crosses where two traits were studied at a time, they were found to be inherited independently of each other.	
II. The Gene-Chromosome Theory	After Mendel's work (which was not immediately recognized and accepted) was rediscovered, considerable investigation followed which led to the statement of the gene-chromosome theory of heredity. Among the techniques employed were microscopic examination of dividing cells and breeding experiments with the fruit fly, *Drosophila*.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	The hereditary mechanism proposed as a result of these investigations included the following understandings: . The inheritance of traits is closely correlated with the behavior of chromosomes in sexually-reproducing organisms. The chromosomes contain the genetic determiners in linear sequence. . Each determiner (gene) has a definite position in the sequence of genes on a chromosome. . Homologous pairs of chromosomes thus have paired genes in the same positions in the gene sequence. . These pairs are known as alleles or allelic genes. The proposal of the gene-chromosome theory made it possible to redefine some of the observations made by Mendel.	Review meiosis and relate it to the discussion of the gene-chromosome theory.
A. Dominance	If the two genes of an allelic pair are unlike, the individual possessing this gene combination is said to be heterozygous for the trait with which the genes are associated. If the two genes of the allelic pair are identical (either dominant or recessive), the individual possessing this combination is said to be homozygous for that trait. When an organism is heterozygous for a specific trait, the effects of the dominant gene are observed and those of the recessive gene are not. If one organism is homozygous dominant and another is heterozygous, both would exhibit the dominant trait. The two organisms would have the same phenotype but different genotypes.	Illustrate with examples of crosses involving complete dominance. By convention, capital letters are used to identify dominant alleles and the lower-case form of the same letter is used to identify the recessive allele. e.g., B - dominant allele b - recessive allele The test cross ("back cross") is used to determine whether an organism is homozygous dominant or heterozygous.

Topics	Understandings and Fundamental Concepts	Supplementary Information
B. Segregation and recombination	During gamete formation there is a random segregation of chromosomes due to the events of meiosis. As a result of gametic fusion, new chromosome combinations (consequently, new allelic gene combinations) are likely to be produced.	
C. Independent assortment and recombination	If the genes for two different traits (nonallelic genes) are located on the same chromosome, they are said to be linked and are usually inherited together. Due to the events of meiosis and random gametic fusion, nonlinked genes are inherited independently.	
III. Patterns of Heredity	Geneticists, studying the inheritance of many different traits in many different organisms, have observed a number of different patterns of inheritance and have created models to account for the observed behavior within the framework of the gene-chromosome theory.	
A. Incomplete dominance	Incomplete dominance involves an apparent "blending" of the effects of contrasting alleles. (Consequently, heterozygous individuals do not resemble individuals with either of the homozygous combinations.) Four-o'clocks, Andalusian fowl, and roan cattle exhibit incomplete dominance for some traits.	A somewhat different convention is used for crosses involving incomplete dominance. e.g., R - gene for red pigment formation in red four-o'clocks W - gene for white pigment formation in white four-o'clocks RW - heterozygous pink individual
B. Sex determination	Diploid cells of many organisms contain two types of chromosomes, autosomes and sex chromosomes. In man there are 22 pairs of autosomes and one pair of sex chromosomes. The sex chromosomes are designated "X" and "Y."	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	The sex of an individual is determined at fertilization on the basis of the resultant combinations of X and Y chromosomes. . In humans and fruit flies, XX is the condition in females and XY the condition in males.	In other organisms, such as domestic fowl, males possess two identical sex chromosomes (ZZ) and females two unlike sex chromosomes (ZW).
C. Sex linkage	Genes for certain traits are located on the X chromosome. These traits are said to be sex-linked and do not appear to have corresponding alleles on the Y chromosome. Hemophilia and color-blindness are examples of sex-linked traits in humans.	Pedigree charts may be used to trace sex-linked traits from generation to generation.
D. Multiple alleles	In some instances the observed pattern of heredity cannot be explained satisfactorily on the basis of a single pair of contrasting alleles. It has been possible to devise a satisfactory model in many instances by assuming that more than two alleles are involved in the inheritance of particular traits. Such a model is said to involve multiple alleles. In humans, the inheritance of the ABO blood groups is explained with a model that employs three alleles (I^a, I^b, and i) as follows:	Students should do crosses involving the inheritance of blood groups. Pedigree analysis is also useful here. An alternate convention utilizes the following symbols for the blood group alleles: L^a, L^b, and l.

Blood Group	Genotype
A	I^aI^a or I^ai
B	I^bI^b or I^bi
AB	I^aI^b
O	ii

Topics	Understandings and Fundamental Concepts	Supplementary Information
IV. Mutations	Mutations are genetic changes which are heritable. Mutations that do not effect the sex cells cannot be passed on to offspring by sexual reproduction. However, mutations occurring in autosomes may be perpetuated within an individual as a result of mitotic cell divisions. Most mutations are recessive and are disadvantageous to the organism.	
A. Types		
1. Chromosomal mutations	A chromosomal mutation is a change in a chromosome structure or in the numbers of chromosomes. The effects of chromosomal mutations are often visible in the phenotype of an organism because many genes are usually involved.	
a. Crossing-over	At times, during synapsis in the first meiotic division, chromatids of homologous chromosomes overlap at one or more points. When disjunction occurs, portions of one chromatid may be exchanged for corresponding portions of another chromatid. Since different alleles may be transferred, chromosome composition is changed.	
b. Nondisjunction	Sometimes entire chromosomes fail to separate from one another during disjunction. This results in gametes with more (or fewer) than the normal n chromosome number. After gametic fusion, new individuals may have more, or less, than the normal $2n$ chromosome number. Example: In humans, Down's syndrome (mongolian idiocy) results from nondisjunction of chromosome number 21.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
c. Polyploidy	Occasionally meiosis fails to occur during gamete formation. The resulting $2n$ gamete sometimes succeeds in fusing with a normal n gamete, producing a $3n$ individual. (If two $2n$ gametes fuse, a $4n$ individual results.) Such individuals often exhibit exaggerated characteristics such as those in "double" zinnias.	
d. Other chromosomal mutations	Other unusual alterations in chromosome composition may result from random breakage and recombination of chromosome parts during the early stages of the first meiotic division.	Recently, evidence has begun to accumulate that suggests that the hallucinogenic compound LSD promotes chromosomal breakage, hence, heritable mutations.
2. Gene mutations	A gene mutation involves a change in the chemical nature of a gene. Often the effects of gene mutations are subtle and not readily observable. In some instances, however, gene mutations may be dramatic, as in the case of the gene which determines albinism.	See section VII, C in the MG extension of this unit for a biochemical explanation of gene mutations.
B. Mutagenic agents	Mutations may be caused by such agents as: . Cosmic rays . X-rays . Ultraviolet rays . Radiation from radioactive substances . Compounds such as mustard gas or colchicine	
V. Interaction of Heredity and Environment	The environment plays an interacting role in the development and expression of inherited traits.	
	The relationship between gene action and environmental influence has been studied in many organisms. Examples include: . the effect of temperature on curled wing condition in *Drosophila*	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	. the effect of temperature on hair color in the Himalayan hare . twin studies	
VI. Heredity and Man		
A. Human genetics	The principles of genetics appear to hold for all organisms including man. Acquisition of knowledge of human genetics has been limited because man is a difficult subject for genetic experimentation. A prolonged period of physical development and a sparsity of offspring are two of the problems encountered. Some human traits that have been studied include phenylketonuria, sickle-cell anemia, and blood group inheritance.	
1. Phenyl-ketonuria	Phenylketonuria (PKU) is a condition characterized by feeblemindedness and has been shown to occur when an individual is homozygous with respect to a particular mutant gene. The symptoms of the disease apparently result from the gene-induced inability to synthesize a single enzyme necessary in the metabolic activity associated with proper brain function.	
2. Sickle-cell anemia	A condition known as sickle-cell anemia is common among certain African populations. Afflicted individuals inherit an abnormal hemoglobin which imparts the peculiar "sickle" shape to red blood cells. Sufferers of the disease often die at an early age. It has been determined that the abnormal hemoglobin differs from normal hemoglobin by only a single amino acid. The abnormality is found in individuals who are homozygous with respect to a particular mutant gene.	Heterozygous individuals sometimes show mild symptoms of the disease. In addition, heterozygous individuals have a higher than normal resistance to malaria. This relationship has tended to maintain the otherwise harmful gene in African populations.

Topics	Understandings and Fundamental Concepts	Supplementary Information
3. Blood groups	The inheritance of the ABO blood groups in man is best explained by assuming that three alleles are involved in the expression of the trait, no individual possessing more than two of the three.	See section III, D in this unit.
B. Plants and animal breeding	Principles of genetics have been used by man to improve and produce new varieties of plants and animals. Artificial selection, inbreeding, hybridization, and the maintenance of desirable mutations by vegetative means (grafting, for instance) are widely used.	
VII. Modern Genetics	In recent years, biochemists have found that the nucleic acid DNA (deoxyribonucleic acid) is the chemically active component of the gene. (RNA is the genetic material of some viruses.)	
A. DNA as the hereditary material		
1. Evidences	DNA has been demonstrated experimentally to be the chemical basis of heredity. . Experimental evidence involving bacterial transformations indicates that isolated DNA can bring about hereditary changes usually associated with the gene. . Evidence from research involving bacteriophages (bacterial viruses) has also pinpointed DNA as the hereditary material. In order to understand the chemical nature of the gene, the chemical structure of DNA must be understood.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
2. DNA structure	DNA, usually found in the nucleus of cells, is a large molecule consisting of thousands of smaller units known as nucleotides.	
a. Nucleotides	A DNA nucleotide is composed of three parts: . phosphate . deoxyribose (a 5-carbon sugar) . nitrogenous base (adenine, thymine, guanine, or cytosine)	Adenine and guanine are purines, and thymine and cytosine are pyrimidines.
b. Watson-Crick model	Watson and Crick, using X-ray diffraction data supplied by Wilkins, developed a model of the DNA molecule constructed of nucleotides. This model helps to explain how DNA replicates and how genetic continuity is maintained. . The proposed DNA molecule has a "ladder" type organization. This "ladder" is thought to be twisted in the form of a double helix. . The uprights of the "ladder" are composed of alternating phosphate and deoxyribose molecules. . Each rung is composed of pairs of bases held in association by relatively weak hydrogen bonds. Base pairs are restricted to adenine - thymine and guanine-cytosine combinations.	
MG		
B. Gene action	The two principal actions of genes are: . maintaining genetic continuity by means of replication . controlling cellular activity by producing specific enzymes	
1. DNA replication	DNA is believed to replicate in the following manner during the processes of mitosis and meiosis: . Double-stranded DNA unwinds and "unzips" along the weak hydrogen bonds between the base pairs.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	. Free nucleotides are incorporated, in sequence, forming two double strands of DNA which are identical to each other and to the original DNA molecule.	The work of Meselson and Stahl using N^{15} may be mentioned as experimental support for the model of replication.
2. Gene control of cellular activities	The control of cellular activities by DNA involves the nucleic acid RNA (ribonucleic acid).	
a. RNA	RNA, like DNA, is composed of nucleotide building blocks. Three major differences between the structure of DNA and RNA are: . In RNA, ribose is substituted for deoxyribose. . In RNA, uracil is substituted for thymine. . RNA is single-stranded while DNA may be either double- or single-stranded, depending on the phase of its activity. Messenger RNA and transfer RNA are two functionally different types of RNA.	
b. DNA and RNA codes	It is postulated that there is a genetic code which has a four-letter alphabet: . DNA - A, T, C, G . RNA - A. U, C, G Both DNA and RNA codes are based on sequences of three of these letters or multiples of three letters.	Emphasize the large number of three-letter combinations that are possible.
c. Protein synthesis	DNA serves as a template for the synthesis of messenger RNA from free RNA nucleotides.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	The messenger RNA molecules, carrying a specific code determined by the base sequence of the original DNA molecule, move from the nucleus to the cytoplasm where they become associated with ribosomes. Transfer RNA molecules pick up and transfer amino acids from the cytoplasm to the ribosomes. At the ribosomes, particular polypeptide chains are formed as the amino acids are bonded in a sequence determined by the base sequence of the template messenger RNA.	The messenger RNA is a "reverse copy" of the DNA which produced it.
d. The "one gene - one enzyme" hypothesis	A current hypothesis called the "one gene - one enzyme" hypothesis proposes that the synthesis of each enzyme in a cell is governed by the action of a single gene.	Beadle and Tatum's work with *Neurospora* might be briefly discussed. Recent evidence suggests that the hypothesis might better be stated as the "one gene - one polypeptide" hypothesis.
e. Individuality of organisms as related to their DNA and RNA codes	Since the code of DNA determines the code of messenger RNA, DNA determines the sequence of the amino acids in specific proteins. The specificity of enzymes is dependent on their protein makeup, and, since the individuality of a cell is largely a function of the enzymes it possesses, it is evident that DNA determines the individuality of an organism.	
C. Gene mutations		
1. Characteristics	Gene mutations may be interpreted biochemically as any change that affects the base sequence in an organism's DNA.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
2. Mechanisms	Gene mutations include addition and deletions of bases in the DNA sequence, as well as substitutions of single bases.	
D. Cytoplasmic inheritance	In recent years, evidence has begun to accumulate which suggests the presence of hereditary systems outside the chromosomes of the cell nucleus. The pattern which appears to be emerging is that cytoplasmic structures (such as chloroplasts and mitochondria) contain separate genes which are regulated by the nuclear genes.	Investigations of "killer" strains of *Paramecium* and the recent discovery of small amounts of DNA in chloroplasts may be described in support of cytoplasmic inheritance.

Topics	Understandings and Fundamental Concepts	Supplementary Information
I. Evidences for Evolution	Study of past and present organisms indicates that many new species have arisen during the long period of the earth's history. Many species exhibit similarities which suggest common ancestry. Evidences supporting the concept of organic evolution as a reason for the similarities and diversities among species can be observed in the study of: the fossil record, comparative anatomy, comparative embryology, comparative biochemistry, and the geographic distribution of organisms.	
A. The fossil record	The preserved remains of many organisms have been recovered from rock layers which were formed during the remote history of the earth. Fossil characteristics suggest a pattern of relationships which have undergone a process of consecutive change throughout long periods of time. To use the fossil record as evidence for evolution it must be assumed that in undisturbed layers of the earth's crust, the oldest layers are the lowest ones, and each succeeding layer is "younger" than the layer on which it is superimposed. Acceptance of this assumption is the basis for studying serial records of fossils.	This is a readily understood example of an assumption, and the role of assumptions in scientific work can be emphasized here.
B. Comparative anatomy	A comparative study of certain organisms shows striking similarities in anatomical features. In many instances skeletal comparisons suggest development from a common ancestral form, along evolutionary lines reflecting the particular environment in which the related organs function. Such homologous structures include . the forelegs of frogs and horses . the flippers of whales and the arms of man . the wings of bats and birds	

Topics	Understandings and Fundamental Concepts	Supplementary Information
C. Comparative embryology	Comparison of embryonic structures among groups of organisms indicates similarities which strongly suggest common ancestry. . Similarities of vertebrate embryos in early development . Resemblance of some mollusk larvae to annelids	
D. Comparative biochemistry	Biochemical similarities among organisms also support the idea of common ancestry. . The closer the relationship among organisms the greater the similarity of nucleic acids. . Many related organisms have the same enzymes and hormones.	
E. Geographic distribution	Geographic isolation of organisms over the earth increases the likelihood of genetic differentiation. . Darwin's finches . Abundance of marsupials in Australia . Similarities and differences of Old World and New World monkeys	
II. Theories of Evolution	Men have studied the variety of life for centuries. As a result, various theories have been developed to explain the cause of the diversity of organisms, as well as the reasons for their adaptations (structures related to functions). Several of these theories have had great impact on evolutionary thought.	
A. Lamarck's theory of use and disuse	Lamarck believed that new organs arise according to the needs of an organism and that the size of organs is due to the degree to which they are used or not used. He also thought that useful characteristics acquired in one generation may be transmitted to the next.	The error of Lamarck's theory should be emphasized, i.e., assigning purpose to evolutionary change.

Topics	Understandings and Fundamental Concepts	Supplementary Information
B. Darwin's theory of natural selection	Darwin published his theory after many years of observation and careful deduction. Darwin's theory includes these contributory ideas: . More offspring are produced than can possibly survive. . Since the number of adults in populations tends to remain constant from generation to generation, a struggle for survival is suggested. . The individuals that survive are the ones best fitted to exist in their environment, due to differences (variations) in their characteristics. . Individuals that survive tend to reproduce their kind, transmitting their favorable variations to their offspring. . As time and generations continue, the favorable changes (adaptations) are perpetuated in the species.	Darwin's observations and the logic of his thought are examples which illustrate the time and patience required for developing valid scientific theories.
C. Modern theory	Modern evolutionary theory retains the basic essentials of the Darwinian theory, and has added additional information resulting from investigations which followed Darwin's work. The years since the publication of Darwin's theory have seen great advances in the understanding of the genetic basis of evolutionary change.	
1. Production of variations	The genetic basis for variations within a species is apparently provided by gene mutations, chromosome mutations, and the sorting out and recombination of genes associated with sexual life cycles.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
ME		
2. Population genetics	In recent years geneticists have applied the principles of Mendelian genetics to the study of the behavior of genes in populations of sexually reproducing organisms.	
a. Population	A population includes all members of a species inhabiting a given location.	
b. Gene pool	The gene pool of a population consists of the sum total of all the heritable genes for all the traits in a given population.	
c. The Hardy Weinberg principle	Hardy and Weinberg extended the principles of Mendelian genetics to populations of sexually-reproducing individuals and made the following observations: . The gene pool of a population tends to remain stable (i.e., gene frequencies remain constant) if certain conditions are met, including: . large populations . random mating . no migration . no mutations . After one generation of random mating, the genotypes in a population will tend to distribute according to the relationship. $p^2 + 2pq + q^2$. In this relationship, p = the frequency of the dominant allele (A) and q = the frequency of the recessive allele (a). Thus, p^2 = the frequency of homozygous dominant (AA) individuals, 2pq = the frequency of heterozygous (Aa) individuals, and q^2 = the frequency of homozygous recessive (aa) individuals in the population.	It is apparent that the total of all (100% = 1) genotypes in the population would be indicated by the expression $p^2 + 2pq + q^2 = 1$.

Topics	Understandings and Fundamental Concepts	Supplementary Information
3. Transmission of variations	The constancy of a population suggested by the Hardy-Weinberg principle rarely occurs since some or all of the conditions for gene pool stability may not be met. The unstable gene pool that results tends to produce change in the population. The change that results is dependent on the pattern of transmission of variations that arise in the population as acted upon by the environment of the individuals in the populations.	
a. Factors influencing transmission	The principal forces influencing the pattern of change in a population are the environment and isolation.	
(1) The environment	The distribution of alleles in a population tends to reflect the adaptive value of the traits controlled by the alleles. Traits which offer high survival value to individuals possessing them tend to increase in frequency. Traits, and the alleles associated with them, that have low adaptive value tend to have a low frequency of occurrence. If environmental conditions change, selective forces then act on the gene pool of a population in a different manner, and gene frequencies (hence, traits) may change markedly. Traits that formerly had low survival value may, in a changed environment, have greater survival value and increase accordingly. Conversely, high frequency traits may diminish considerably (even disappear) in a changed environment.	
(2) Isolation	Some members of a population may become separated from the original, continuous population. If a	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	population becomes subdivided, transmission of variations is not likely to follow the same pattern in the subdivisions. . Mutations are not likely to be the same. . Random recombination will not be likely to occur in the same manner. Geographic isolation, reproductive isolation, and isolation in time prevent the intermingling of traits within a species and tend to maintain differences.	
b. Patterns of change	Species tend to change in time as random events (mutations and recombination) occur against a background of environmental change and isolation.	
(1) Change within a species	Throughout time most species have changed as environmental conditions have varied and selective forces have increased or diminished the survival value of various traits. Examples: . occurrence of antibiotic-resistant strains of bacteria . occurrence of DDT-resistant house flies	
(2) Development of new species	According to present thinking, new species evolve as a result of the interaction of the following factors: . variations . changes in existing environments . migrations to new environments . adaptation to changed or new environments . natural selection . isolation from other species with which they might interbreed if not isolated	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	When members of one species are geographically isolated, selection tends to act upon separate patterns of randomness to produce divergent trends which may ultimately result in changed individuals. Such changed organisms may become incapable of interbreeding and producing fertile offspring. When such reproductive isolation occurs, two species are said to exist.	
	The pattern of species formation is not thought to be entirely random. Since new species stand a better chance of survival if they are not in direct competition with existing species, they tend to evolve so as to occupy those environmental conditions which are least utilized in the area where they exist. Such a pattern of evolution, where species tend to develop to fill the available environmental niches, is said to be a pattern of adaptive radiation.	The evolutionary pattern of Darwin's finches is an excellent example of adaptive radiation.
III. A Modern Classification System	The great diversity of organisms present on the earth today are the result of billions of years of evolution. Biologists, in attempting to "sort out" and comprehend relationships among this vast number of different types have found it essential to devise systems by which organisms may be classified. A useful classification system should reflect evolutionary similarities and differences, but since so much of the evolution story is not clearly understood, there is some disagreement as to the best classification system.	
	In one modern system, organisms are grouped into three kingdoms, each of which is subdivided into phyla (singular, phylum) which are categories indicating major differences in organization and function.	The terms kingdom, phylum, genus, and species should be understood.

Topics	Understandings and Fundamental Concepts	Supplementary Information
	The three kingdoms are Protist, Plant, and Animal.	
	Protists: . Protozoa . Algae . Fungi . Slime-molds . Bacteria	Representatives of the major phyla should be studied in the laboratory to demonstrate the diversity of life.
	Plants: . Bryophytes . Tracheophytes	
	Animals: . Sponges . Coelenterates . Flatworms . Roundworms . Segmented worms . Mollusks . Arthropods . Echinoderms . Chordates Fish Amphibians Reptiles Birds Mammals	

Topics	Understandings and Fundamental Concepts	Supplementary Information
IV. Origin and Early Evolution of Life	Modern evolutionary theory also includes an explanation for the origin and early evolution of life on the primitive earth.	
A. The heterotroph hypothesis	The heterotroph hypothesis is an explanation for the origin of life, which holds that the first life was not able to synthesize its own organic nutrient materials from inorganic compounds. Like all scientific explanations of incompletely understood phenomena, the heterotroph hypothesis is based on logical extensions of certain basic assumptions.	
1. Assumptions		
a. Raw materials	It is assumed that the primitive earth was an exceptionally hot body consisting of inorganic compounds in solid, liquid, and gaseous states, and a rich environmental supply of energy.	
(1) Inorganic compounds	Water, condensing and falling as rain, carried dissolved gases and minerals to seas in depressions in the cooling earth's crust. In addition to dissolved minerals, the primitive oceans contained concentrations of dissolved ammonia, methane, and hydrogen.	Although methane (CH_4) is usually considered an organic compound, it is thought to have been produced through inorganic chemical activity on the primitive earth.
(2) Energy sources	In addition to heat, energy in the form of lightning discharges from the atmosphere, solar radiation (including X-rays and ultraviolet), and "hard" radiation from crustal rocks offered an energy-rich environment.	
b. Synthesis	Available energy permitted the formation of chemical bonds among dissolved particles in the "hot thin soup" of the seas. Such random synthesis led to the formation of organic molecules such as simple sugars and amino acids. These organic molecules interacted to form more complex organic molecules.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
c. Nutrition	Some of the large, complex molecules formed aggregates (clusters). These aggregates probably incorporated molecules from the seas as "food" (heterotrophic nutrition).	
d. Reproduction	In time, as aggregates became increasingly complex and highly organized, the ability to reproduce evolved. The aggregates are considered to have been alive when they evolved reproductive capacity.	
B. Heterotroph to autotroph	It is thought that heterotrophs evolved a pattern of respiration similar to the anaerobic process of fermentation. Extended periods of fermentative activity would have added quantities of carbon dioxide to the environment.	
	Some heterotrophs evolved a means of using the carbon dioxide to synthesize organic compounds. These were the pioneer autotrophs.	
C. Anaerobe to aerobe	Autotrophic activity tended to add oxygen to the environment.	
	Some autotrophs and heterotrophs evolved mechanisms for using oxygen for deriving energy (aerobic respiration).	
	Modern organisms may be heterotrophic aerobes or anaerobes, or autotrophic aerobes or anaerobes.	
	The evolution of the first life to the great variety and complexity of life that exists today required billions of years of slow change.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
I. Ecology	Ecology is the study of the interactions of plant and animals, and their interrelationships with the physical environment. No organism exists as an entity, separate and distinct from its environment, since a dynamic equilibrium exists in the interactions of organisms with themselves and with the environment.	
A. Physical factors in the environment	Various physical and chemical factors affect the ability of an organism to live and reproduce in any location. These nonliving, or abiotic factors, include: . light . temperature . moisture . substratum (soil or rock) . available inorganic substances, such as minerals . oxygen supply	
B. Biotic factors in the environment	The interactions of organisms (biotic factors) influence the development and survival of each other and of the species.	The term *organism* implies a prime characteristic of the living world - ORGANIZATION - which is evident from the atom to the biosphere. The concept of organization is apparent in: . atoms . inorganic molecules . large organic molecules . nucleic acids . chromosomes

Topics	Understandings and Fundamental Concepts	Supplementary Information
		. viruses . cells . tissues . organs . organ-systems . organisms . populations . communities . ecosystems . world biomes . biosphere
II. Biotic Organization		
A. Population	All members of a species inhabiting a given location constitute a population. A species is a group of organisms that are more or less alike. They are capable of interbreeding and producing fertile offspring under natural conditions.	Consideration of ecological principles at certain levels of biotic organization facilitates understandings which can be applied to all levels.
B. Community	A unit composed of all plant and animal populations interacting in a given environment is known as a community.	
C. Ecosystem	The living community and nonliving environment function together as an ecological system, or an ecosystem.	
1. Interactions	An ecosystem involves interaction among organisms, as well as a flow of energy and a cycling of materials. Examples: a balanced aquarium, a self-contained space ship.	
a. Specific relationships	Various species of organisms that live in the same area, and are thus part of the same ecosystem, affect each other in a variety of ways. This may be illustrated by the interactions involving nutrition.	

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Organisms which cannot synthesize their own food are said to be dependent, meaning dependent upon other organisms for food. This dependency is shown by:

- saprophytes, the plants which live on dead organic matter. These include the decomposers upon which all organisms depend, directly or indirectly. Examples: bacteria of decay, mushrooms
- herbivores, the plant-eating animals. Examples: cows, horses
- carnivores, the flesh-eating animals. These include:
  - predators, animals which kill other living animals and feed on them. Examples: lions, hawks
  - scavengers, animals which eat organisms that they have not killed. Examples: vultures, hyenas
- omnivores, animals that eat both plants and animals. Example: man

Different organisms may live together in a close association which may or may not be beneficial to them. This living together in intimate association is known as symbiosis.

Types of symbiosis include:

- commensalism - one organism is benefited and the other is not affected. Examples: remora and shark, barnacle and whale
- mutualism - both organisms benefit from the association. Examples: alga and fungus in a lichen, nitrogen-fixing bacteria and legumes
- parasitism - the parasite benefits at the expense of the host. Examples: athlete's foot fungus and man; lamprey eel and trout

Supplementary Information

Some animals may be both scavengers and predators as, for example, the snapping turtle.

Topics	Understandings and Fundamental Concepts	Supplementary Information
		Devices may be used to clarify the relationships: Commensalism (+0) Mutualism (++) Parasitism (+-) Associations among living things are not always well-defined or permanent.
	Competition occurs when organisms living in the same environment utilize the same limited resource, such as food and space, and other environmental factors as water, light, oxygen, and minerals. The more similar the requirements of the organisms involved, the more intense is the competition. If two different species compete for the same food or reproductive sites, one or the other, due to differences in reproductive rates, will be successful in eliminating the other. This establishes one species per niche in a balanced (climax) community. All members of that species use the same kinds of food and occupy similar reproductive sites.	The term habitat refers to where organisms live; the term niche refers to their role in the biotic community.
b. General relationships		
(1) Energy flow	Activity is characteristic of life and requires the expenditure of energy. The complex pathways of energy through the living components of the ecosystem are represented in the concept of the food chain and web. Energy from the sun enters living systems through green plants. A food chain involves the transfer of food energy from the source in green plants through a series of organisms with repeated stages of eating and being eaten.	

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In a natural community the flow of energy (and materials) is really much more complicated than is suggested by any one food chain, since practically all species of organisms may be consumed by more than one other species. Therefore, there are so many branchings and cross-branchings among the food chains of any community that the whole situation is better termed a food web.

Balance is achieved in a food web by interactions among:

- producers — All of the food for a community is derived from organic compounds synthesized in green plants. Green plants are, therefore, considered to be producers.
- consumers — Organisms that feed directly upon green plants (herbivores) are known as primary (or first-level) consumers. Secondary (or second-level) consumers (carnivores) prey upon primary consumers and gain their food and energy from them.
- decomposers — Living organisms concentrate and organize materials of the environment into complex living substances. During their lifetime they give off wastes. Wastes and dead organisms are eventually broken down to simpler compounds by decomposers. These compounds are thus returned to the environment where they can be used by other living organisms.

In going from the producer through the various members of a food web, the total amount of energy is decreased, since each member of the web utilizes some of this energy in consuming source material and for its own metabolism, and gives off additional energy in the form of heat.

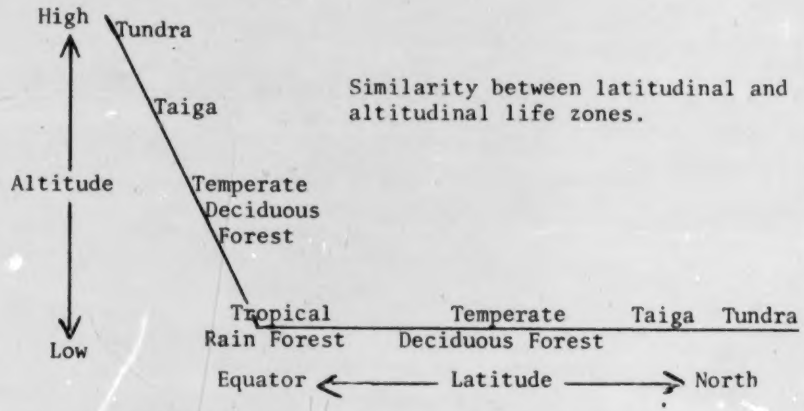
Supplementary Information

This concept is often referred to as the pyramid of energy.

Topics	Understandings and Fundamental Concepts	Supplementary Information
	Since there is a loss of energy at each feeding level, the producer organisms contain the greatest amount of energy. Energy is steadily expended and a system cannot continue functioning without the constant input of energy from the outside.	
	Consumers are usually larger than the organisms they eat. As a consequence, many organisms at a lower feeding level are required to furnish sufficient materials and energy to supply a single organism at a higher feeding level.	This concept is often referred to as the pyramid of numbers.
(2) Material cycles	Material is cycled between organisms and their environment, passing from inorganic sources to organic forms and back again to inorganic forms. This is accomplished chiefly through the action of decomposers, scavengers, and saprophytes.	
	The nitrogen cycle is an example of a materials cycle.	Additional examples of material cycles include the carbon, oxygen, hydrogen, and phosphorus cycles in nature.
	The Nitrogen Cycle:	
	Nitrogen is bound in the protoplasm of living things during protein synthesis.	
	The nitrogen of protein is released and converted to nitrates by the sequential activities of certain bacteria: the decay and nitrifying bacteria. Nitrogen-fixing bacteria also produce nitrates from gaseous nitrogen. Thus, nitrogen in the form of nitrates is made available to plants for protein synthesis.	
	Animals eat plants and synthesize animal protein from plant protein.	
	Plants and animals produce nitrogenous wastes during their lifetime and become sources of energy for the decomposers (bacteria of decay) when they die.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	Denitrifying bacteria contribute to the cycle by returning molecular nitrogen to the atmosphere.	
2. Maintenance	An ecosystem is self-sustaining if there is: . a constant source of energy . a living system capable of incorporating this energy into organic compounds . a cycling of materials between organisms and their environment	
3. Changes	A self-perpetuating community in which populations exist in balance with each other and with the environment is said to be stable. Such a stable, or climax community - the living part of an ecosystem - persists until major climatic, geologic, or biotic changes alter or destroy it, thus producing nonclimax conditions.	
	Thereafter, a community goes through a series of successive stages until climax conditions are reached.	
	Each community modifies the environment, making it more unfavorable for itself, and, apparently, more favorable for the following community.	
	This replacement of one community by another until a climax stage is reached is known as ecological succession.	
	Successive communities are composed of populations able to exist under the prevailing conditions and are identified by their dominant species - the one which exerts control over the other species present.	For example, in a grassland community, grass is the dominant species, since it is the kind of plant that can grow in those climatic and soil conditions.

Topics	Understandings and Fundamental Concepts	Supplementary Information
	Dominant plant species also dominate in the sense that they are the most abundant food present. Animal populations are limited to those which can use these plants (or each other) for food.	
a. Pioneer organisms	Succession may be said to begin with pioneer organisms, since these are the first plants to populate a given location. Lichens, for example, are pioneer organisms on bare rock.	
	Since the pioneer organisms change the environment, habitats for other organisms are developed.	
b. Climax community	The climax community is not immediately replaced; long periods of time are required for ecological succession after a major disturbance. In New York State, for instance, climax communities vary. At higher elevations hemlock-beech-maple associations are often the climax flora. At lower elevations, oak-hickory associations are frequently the climax flora.	
	Some disturbances result in changes so drastic that the original climax community never returns.	
EC D. World biomes	A biome represents a major ecological grouping of organisms.	
1. Terrestrial	The major plant and animal associations on land are determined by the major climate zones of the world, modified by local land and water conditions.	Climatic factors including temperature, precipitation, and solar radiation, plus other factors, such as the nature of the earth's crust, determine the habitats for living organisms.

Topics	Understandings and Fundamental Concepts	Supplementary Information
	Land biomes are characterized and named by the climax vegetation in a region. Since green plants are the producers of food, the major plant associations of the earth determine the animals that can live in any locality. The major land biomes are: . tundra . taiga (coniferous forest) . temperate deciduous forest . tropical forest . grassland . desert Increase in latitude or in altitude can bring about similar climatic conditions which result in similar plant associations at higher latitudes and higher altitudes.	 Similarity between latitudinal and altitudinal life zones.
2. Aquatic	The criteria used to classify terrestrial biomes are not applicable to large bodies of water, such as oceans, where the distribution of plants does not exert a controlling influence.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	The temperature variation is not great and moisture is seldom limiting in aquatic areas, which represent the largest and most stable ecosystems on earth.	
	More than 70 percent of the earth's surface is covered by water, and most of the life on the planet exists in conditions where water is the principal external medium.	
	Such physical factors as the quantity of available oxygen and carbon dioxide, temperature, and suspended or dissolved materials are the major factors affecting aquatic organisms.	Aquatic organisms which carry on aerobic respiration utilize atmospheric oxygen which has penetrated and dissolved into the water medium.
		The quantity of oxygen present in any body of water limits the quantity of aerobic life that may live there.
	The greatest amount of food production in the world occurs in the oceans, along the edges of land masses (coastal waters), wherever water is fairly clear.	
a. Marine	The world ocean is a huge, continuous body of water that: . Absorbs and holds large quantities of solar heat and regulates the earth's temperature . Contains a relatively constant supply of nutrient materials and dissolved salts . Serves as a habitat for most organisms	Discuss briefly: . Water absorbs large quantities of heat, compared to all other substances. . Water absorbs heat slowly and loses heat slowly. . Much of the solar heat striking the earth is absorbed by water, keeping earth temperature low.
	The salts of the oceans, dissolved from the land masses, not only furnish nutrients to organisms, but are related to their water balance. In general, salt concentrations in marine environments are very similar to salt concentrations in living cells.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
	The quantity of light available for photosynthesis in the oceans is determined by the intensity of radiation entering the water, quantity of reflection, and transparency of the water. Water absorbs much light energy, so that most photosynthesis takes place near the surface of the oceans, the deeper regions being too dark.	
b. Fresh water	As in marine environments, available respiratory gases, temperature, transparency and depth of the water, as well as salt concentration, affect life in fresh water. Due to the lower concentration of salts in fresh water, a diffusion gradient exists between cells of organisms and their water environment. Water balance in fresh water animals is maintained by regular removal of excess water by means of specialized structures (a homeostatic mechanism).	
C. Biosphere	The biosphere is that portion of the earth in which ecosystems operate, and includes the biologically inhabited air, soil, and water. The term "biosphere" also includes the relationships among living things for the transfer of materials and energy.	
III. Biosphere and Man		
A. Past and present	Man exerts a unique and powerful influence on the physical and living world. He has been enormously successful in modifying his environment. His failures, however, can be attributed to his lack of realization that he not only influences other individuals, other species, and the nonliving world, but is influenced by them.	

Topics	Understandings and Fundamental Concepts	Supplementary Information
1. Negative aspects	The delicate balance of nature has been upset as a result of:	
	. Man's numbers: The population total of humans has risen at a rapid rate partly because of the removal of natural checks on populations. This increase in human population has far outstripped the food-producing capacity of many ecosystems of the world.	Discuss the Theory of Malthus: the rate of increase of any population of living organisms will be inevitably limited due to restrictions imposed by the environment (e.g., food supply). A general population growth curve may be used in the discussion of this topic.
	. Man's activities: Increasing urbanization has claimed increasing amounts of food-producing land.	
	Man has permitted overgrazing, overcropping, and overburning, resulting in the loss of topsoil cover in areas so treated. Removal of soil (and forest) cover has led to disastrous floods.	Many years are required to renew "renewable" resources, such as topsoil.
	Technological activities have polluted two components of the environment on which life depends: air and water. Escalating demands for water (agriculture, sewage disposal, industrial use, hydroelectric power, and recreation) are being made on a supply which is being increasingly polluted. Burning and other industrial processes are the major causes of air pollution.	Pollution has always existed in connection with man's activities; today's pollution problems stem from the magnitude of the pollutants.
	Major water pollutants include: raw sewage, chemicals, fertilizers, silt, and salt water.	Discuss the serious pollution problem which exists in the Hudson River and in Lake Erie.

Topics	Understandings and Fundamental Concepts	Supplementary Information
	Man has led to the extinction or near extinction of many animal species, not only because of direct killing, but also because of human alteration of habitat. Extinct species include: passenger pigeon, great auk, dodo, Carolina paroquet, heath hen. Nearly extinct species include: California condor, grizzly bear, American crocodile, blue whale.	Discuss the present condition of plant and animal life in the Florida Everglades.
	The decline of the Kaibab deer population from 1907 to 1925 illustrates the effects of the removal of normal checks (predators) on species populations.	
	Species of plants also face extinction because of destruction or uncontrolled disease. Examples include: American elm, American chestnut.	
	The use of pesticides (in an attempt to control certain pests) has compounded the pest problem, contaminated the atmosphere and water supply, and disrupted food webs.	The decline of the bald eagle may possibly be attributed to disrupted food webs.
	In the case of insects, mutant species, resistant to insecticides, have increased faster than new insecticides can be developed. Since insects are man's chief competitors for available food, an increase in their numbers represents formidable competition.	It has been established that forage crops can absorb insecticides from the soil, thus entering food chains and webs. Examples of the use of insecticides and their effects on the balance of nature should be cited. For example, DDT was used against the red mite. The red mite was resistant and the DDT killed the predator of the mite, resulting in a population explosion among the red mites.

Topics	Understandings and Fundamental Concepts	Supplementary Information
		It should be emphasized that insect resistance did not develop in response to the insecticide. The insecticide acted as a selecting agent.
	The use of antibiotics in an attempt to control certain pathogens has contributed to the rise of resistant mutant species of pathogens, and has thus compounded the disease control problem.	
	Man has imported organisms, such as the starling and rabbit, which have unexpectedly led to the disruption of existing ecosystems. Global travel increases the dissemination to new environments of pathogens, and insect and plant pests. Examples of imported pests include: the corn borer, Japanese beetle, and Hessian fly	
2. Positive aspects	In some cases man has successfully used ecological knowledge:	
	. Methods of controlling the human reproductive rate are being developed.	
	. The sea is being extensively investigated as a source of food. Since many soil nutrients lost to crop plants are carried out to sea, return by way of marine food may assist in perpetuating cycles.	
	. Reforestation, soil cover plantings, and dam construction serve as flood and soil erosion controls in many areas. Soil reclamation measures have returned otherwise lost soil to use.	
	. Attempts are being made in large cities, like New York, to control air and water pollution by laws and by the development of new techniques of sanitation.	In New York State, programs using ecological principles have been set up to reclaim the contaminated Hudson River.

Topics	Understandings and Fundamental Concepts	Supplementary Information
	. Man has attempted to preserve some plants and animals which are or were on the verge of extinction. Game preserves, national parks, hunting laws, and fisheries represent some efforts by man to preserve species. Animals which were near extinction and which are now increasing in numbers as a result of protection are the bison, egret, and trumpeter swan. The future of some species, such as the California condor, whooping crane, and the redwoods, is still in doubt.	
	. Biological control of insect pests is now being encouraged after extensive studies of the life histories of these pests. This is less likely than the use of insecticides to affect those species of insects which are helpful to man. The undesirable effects of pesticides, in general, may possibly be avoided by the use of carefully considered biological controls. Example: the use of cobalt-60 radiation on male screw worm flies	Rabbit control by biological methods is being used in Australia.
	. Some imported animals, such as the Italian honeybee and the Chinese pheasant, have proved to be extremely valuable in their transplanted environments. . Control of human infectious diseases has led to an increase in the life span of man. . Space exploration includes ecological considerations.	
B. The future	Lack of understanding on the part of man has led to the ecological problems of the past and present. The future rests on man's acknowledgement that the principles of ecology which apply to plants and other animals apply equally to him.	

APPENDIX I

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APPENDIX III

SUGGESTED LABORATORY EXERCISES

UNIT 1

MICROSCOPE - use, parts, functions of parts, and principles

MICROSCOPE STUDY OF POND WATER, or mixed protozoan cultures

DETERMINATION OF PERCENTAGE OF WATER (BY WEIGHT) IN VARIOUS PLANT AND ANIMAL TISSUES, fruits, meats, etc.

MICROSCOPE STUDY OF CORK

OBSERVATION OF CELLS IN PLANT AND ANIMAL TISSUE

MICROSCOPE MEASUREMENT OF VARIOUS CELLS and/or some prominent organelles

UNIT 2

COMPARATIVE STUDIES OF FOOD-GETTING ADAPTATIONS IN VARIOUS ANIMAL GROUPS (especially arthropods)

EFFECT OF TEMPERATURE, pH, CONCENTRATION OF SUBSTRATE, etc., on enzyme action (e.g., salivary amylase, pepsin)

DISSECTION OF GRASSHOPPER

DISSECTION OF EARTHWORM

DISSECTION OF FROG (pithed or anesthetized, if possible)

OBSERVATION OF SOME LIFE ACTIVITIES OF HYDRA

THE USE OF pH INDICATORS ON BIOLOGICAL MATERIAL

DIFFUSION AND OSMOSIS USING MEMBRANES

PLASMOLYSIS OF CELLS

THE EFFECTS OF VARIOUS CHEMICALS ON HEART BEAT (e.g., caffeine, adrenalin, etc., on frog or daphnia heart)

RESPIRATION RATE OF ANIMALS

BLOOD GROUPING (antigen-antibody reaction)

UNIT 3

YEAST OR BACTERIAL FERMENTATION

PHOTOSYNTHESIS (e.g., effects of wavelength of light, quantity of light, CO_2 concentration, etc.)

CHROMATOGRAPHY OF CHLOROPHYLL PIGMENTS

TRANSPIRATION RATE

RADIOACTIVE UPTAKE BY A VASCULAR PLANT

EFFECTS OF GRAVITY ON DIRECTION OF ROOT GROWTH

AUXIN EXPERIMENTATION

DIGESTION IN PLANTS

GROWTH OF A BEAN PLANT: Root growth, stem growth (to demonstrate growth at tips)

UNIT 4

MICROSCOPE STUDY OF MITOSIS in plant and animal cells

MICROSCOPE STUDY OF MEIOSIS

CHICK EMBRYOLOGY

FROG EMBRYOLOGY

REGENERATION IN PLANARIA OR HYDRA

POLLEN TUBE FORMATION

COMPARATIVE STUDY OF FLOWERS (dissection of a variety of different flowers, if possible)

COMPARATIVE STUDY OF FRUITS AND SEEDS

SEED GERMINATION (optimal factors; digestion of stored starch, etc.)

ASEXUAL REPRODUCTION in plants and animals

DISSECTION OF VERTEBRATE REPRODUCTIVE SYSTEMS

GROWTH OF BEAN PLANT from seed to flowering stage, as a study of plant development

UNIT 5

CROSSES INVOLVING DOMINANCE IN DROSOPHILA

TEST CROSS IN DROSOPHILA

CROSSES INVOLVING SEX-LINKAGE IN DROSOPHILA

CROSS OVER ANALYSIS IN DROSOPHILA

THE LAWS OF CHANCE (coins, dice, colored beans)

NUTRITIONAL MUTANTS (neurospora, bacteria, yeast)

GENE FREQUENCY ANALYSIS - PTC paper

VARIATION OF A TRAIT WITHIN A SPECIES

MENDELIAN INHERITANCE IN CORN: purple vs. white grains; sugary vs. starchy grains

UNIT 6

STUDY OF FOSSILS

CLASSIFICATION - the use of a key

COMPARATIVE STUDY OF VERTEBRATE SKELETONS

COACERVATE FORMATION

UNIT 7

STUDY OF CLIMATE-VEGETATION MAPS

STUDY OF POPULATION FLUCTUATION IN A MICROCOMMUNITY (e.g., hay infusion)

FIELD TRIPS TO SHOW ECOLOGICAL PRINCIPLES involving dominant species, pioneer plants, old field succession, etc. Studies of polluted rivers, beach, roadside, parks, school lawns and gardens, etc.

STUDY AND PREPARATION OF CLIMATOGRAMS USING TEMPERATURE-RAINFALL DATA FOR desert, forest, grassland communities

MINIATURE ECOSYSTEM (closed microcommunities, i.e., snail, water-plant, water and light)

STUDY OF SOIL BACTERIA

STUDY OF YEAST POPULATIONS